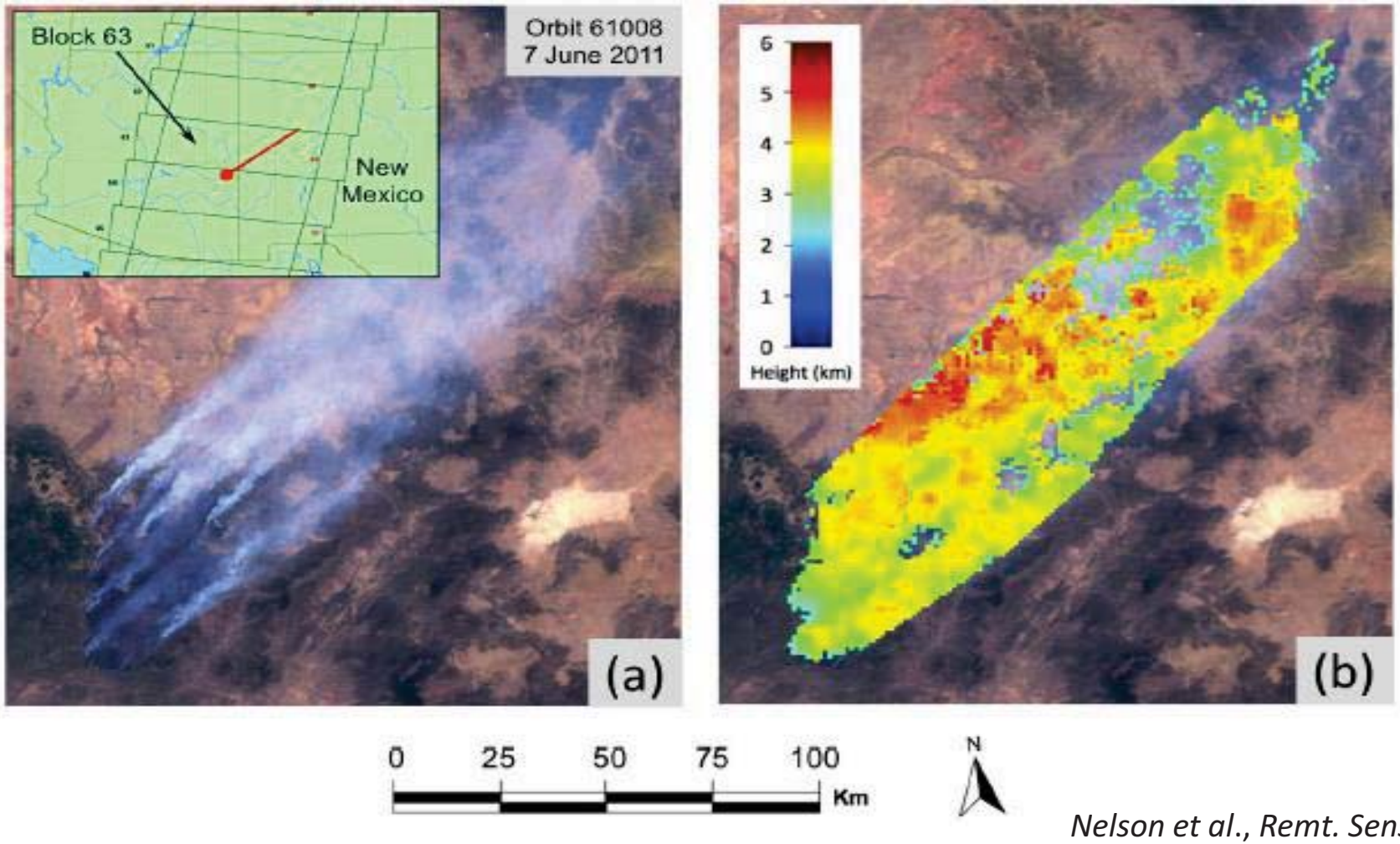
Constraints on smoke injection height, source strength, and transports from MISR and MODIS

Ralph Kahn

NASA Goddard Space Flight Center

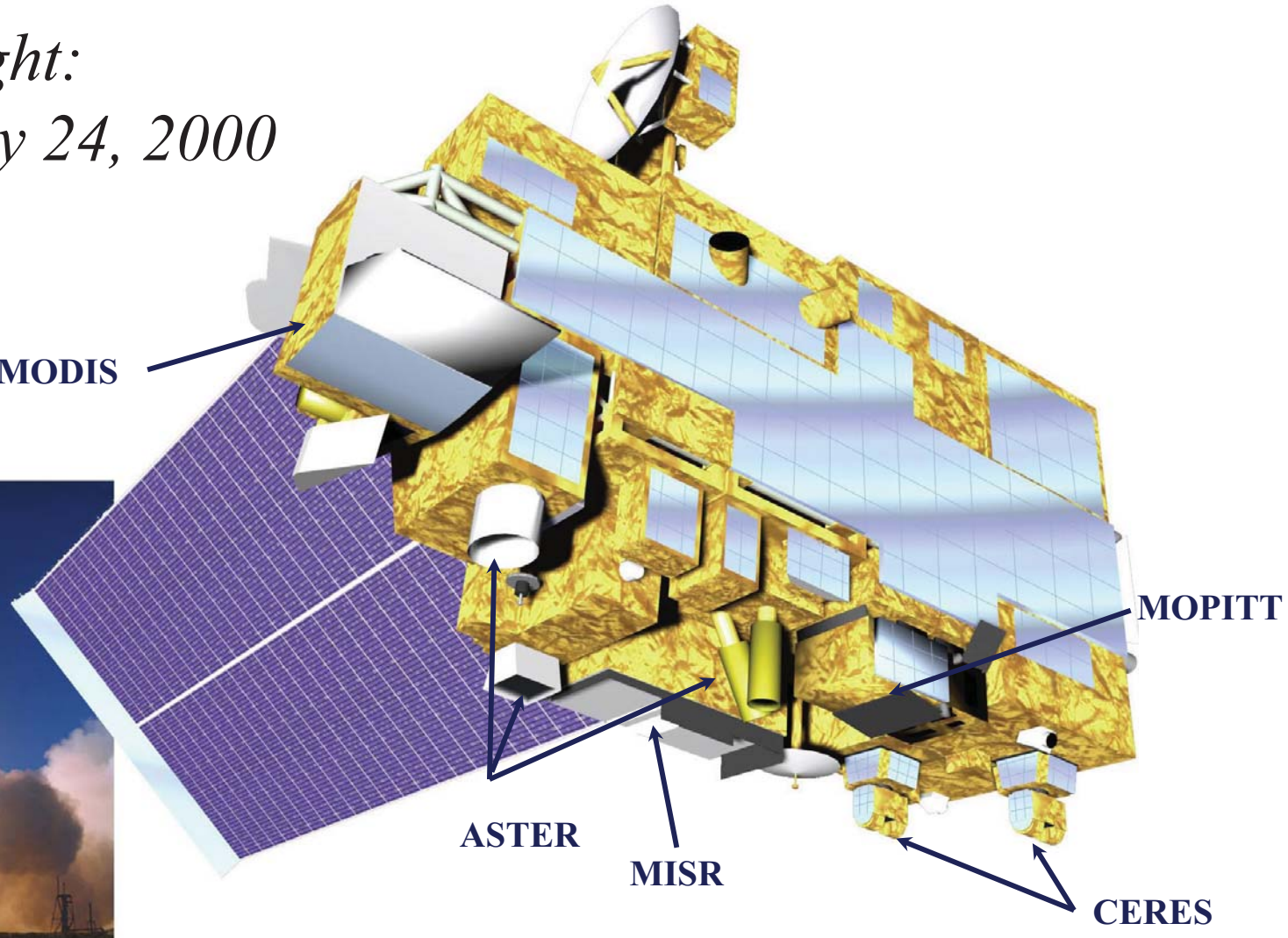
Mariya Petrenko, Maria Val Martin, Mian Chin



Nelson et al., Remt. Sens. 2013

The NASA Earth Observing System's Terra Satellite

First Light:
February 24, 2000



Source: Terra Project Office / NASA Goddard Space Flight Center

Multi-angle Imaging SpectroRadiometer

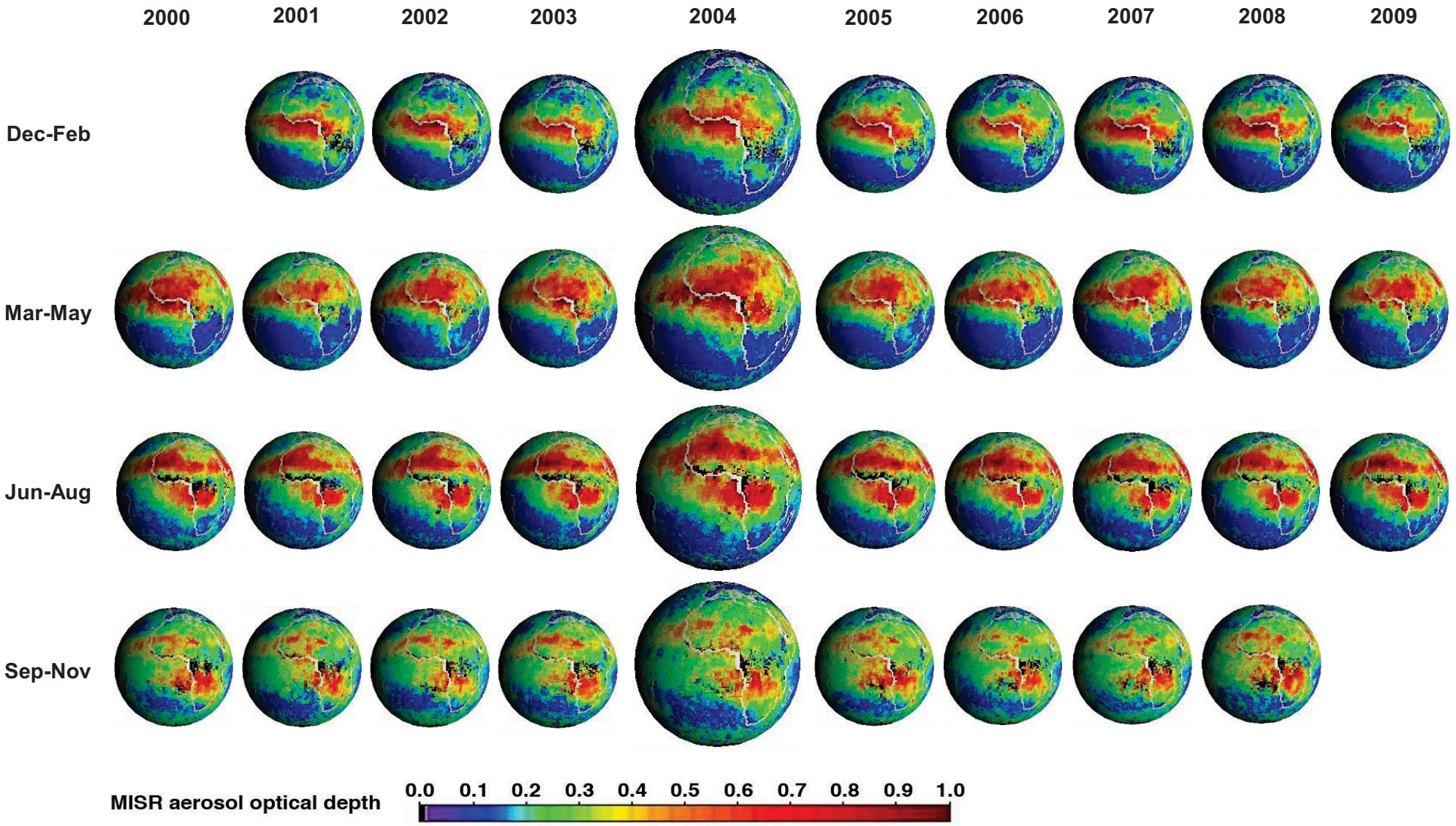
MISR

http://www-misr.jpl.nasa.gov

http://eosweb.larc.nasa.gov

- Nine CCD push-broom cameras
- Nine view angles at Earth surface: 70.5º forward to 70.5º aft
- Four spectral bands at each angle: 446, 558, 672, 866 nm
- Studies *Aerosols*, *Clouds*, & *Surface*

Ten Years of Seasonally Averaged Mid-visible Aerosol Optical Depth from MISR

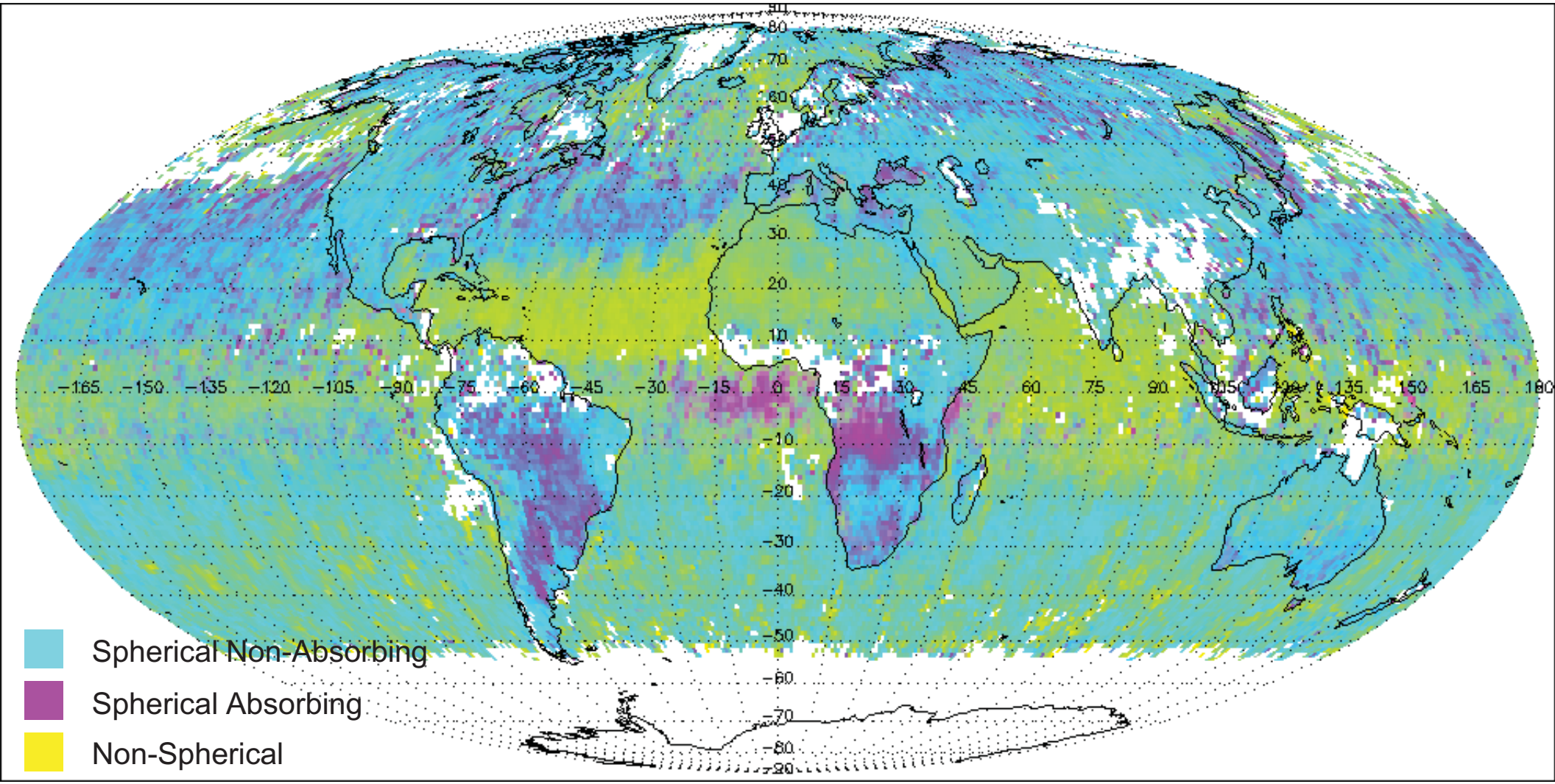


…includes bright desert dust source regions

MISR Team, JPL and GSFC

MISR *Aerosol Type* Distribution

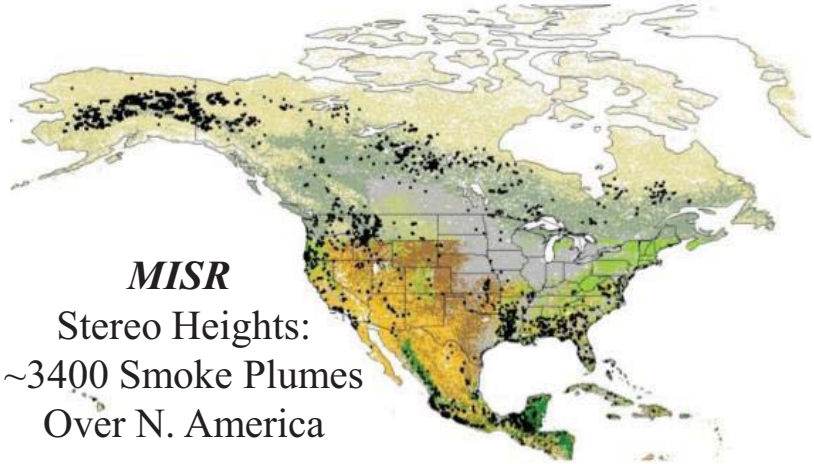
MISR Version 22, July 2007



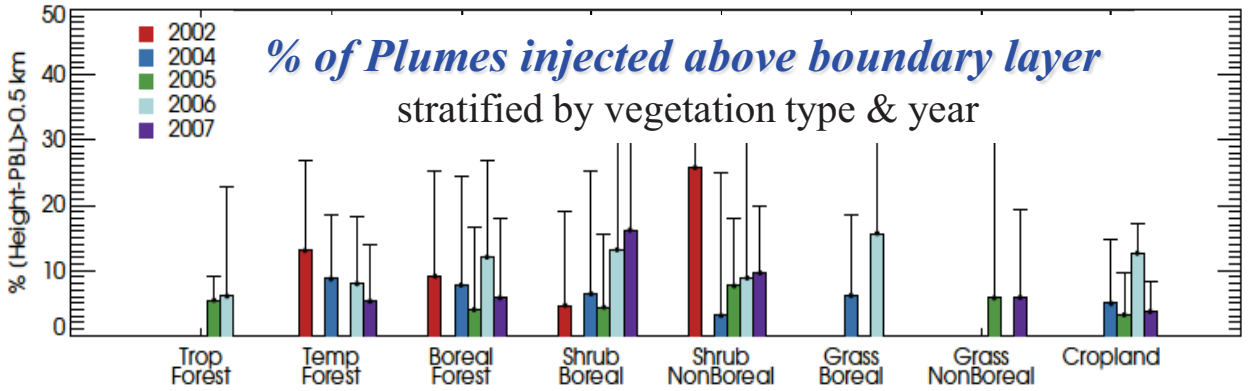
Kahn, Gaitley, Garay, et al., JGR 2010

Wildfire Smoke *Injection Heights* & *Source Strengths*

[These are *the two key parameters* representing aerosol sources in climate models]

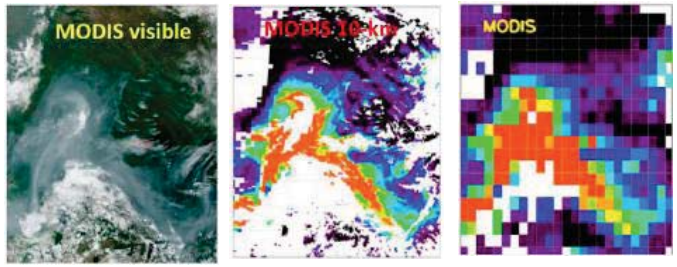


MISR
Stereo Heights:
~3400 Smoke Plumes
Over N. America

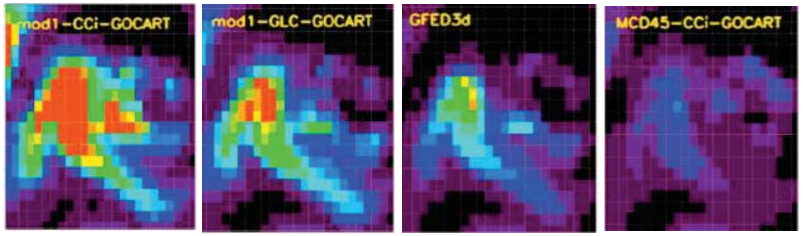


% of Plumes injected above boundary layer
stratified by vegetation type & year

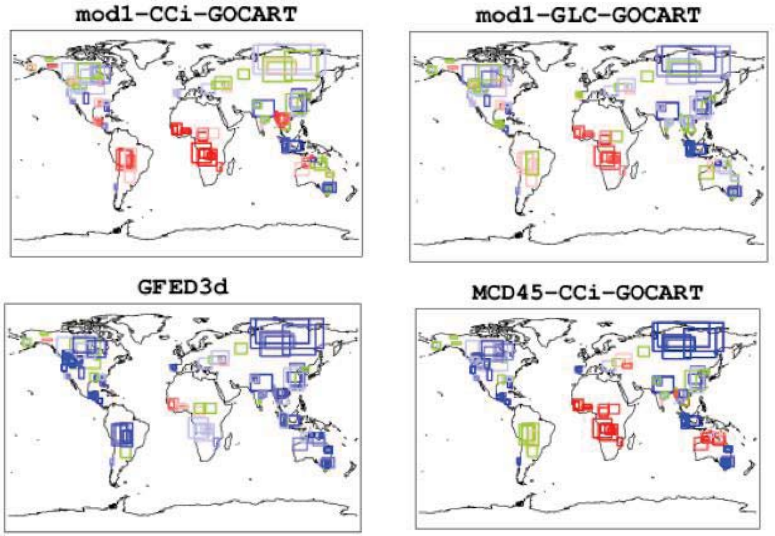
Val Martin et al. ACP 2010



MODIS Smoke Plume Image & Aerosol Amount Snapshots

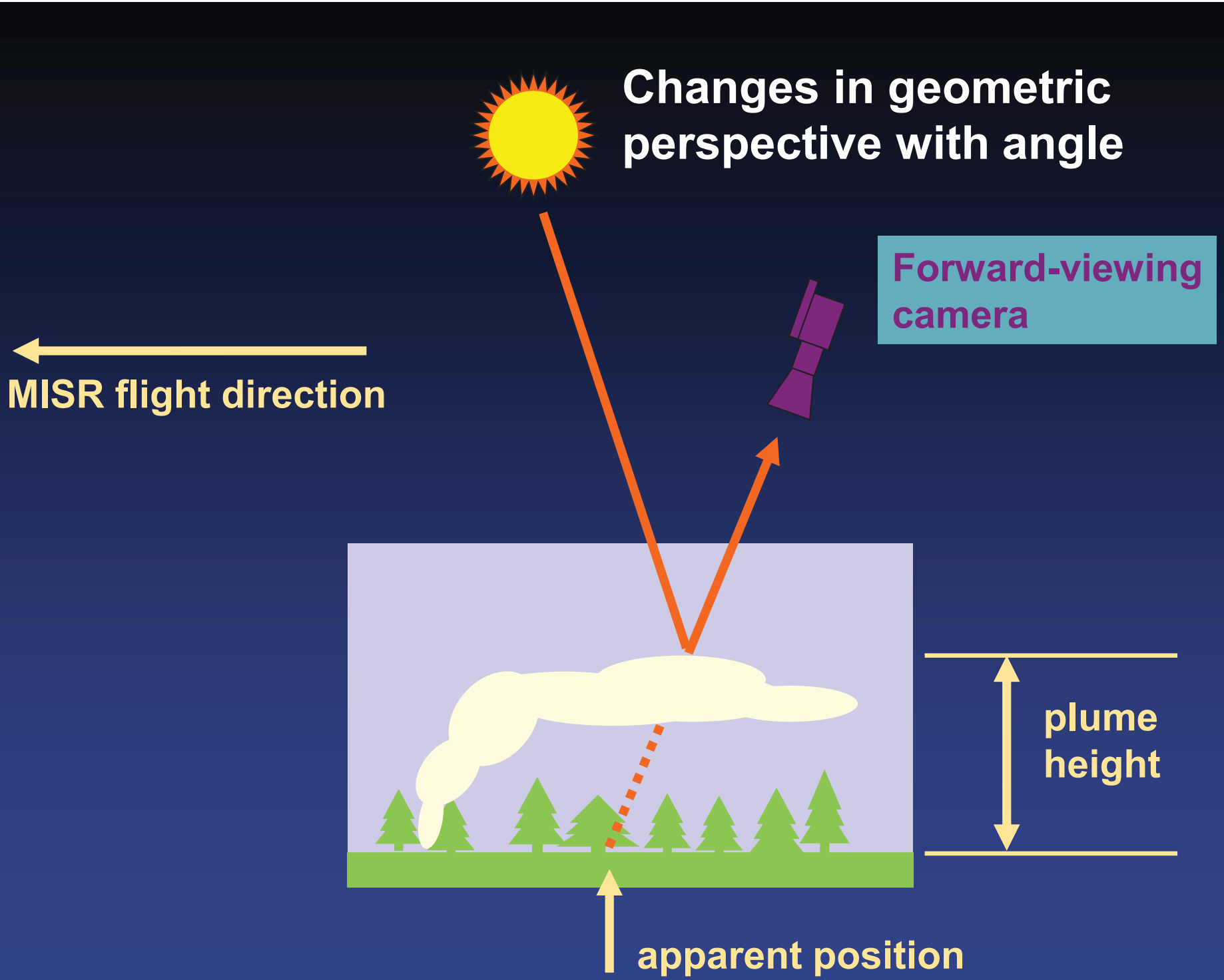


GoCART Model-Simulated Aerosol Amount Snapshots
for *Different Assumed Source Strengths*

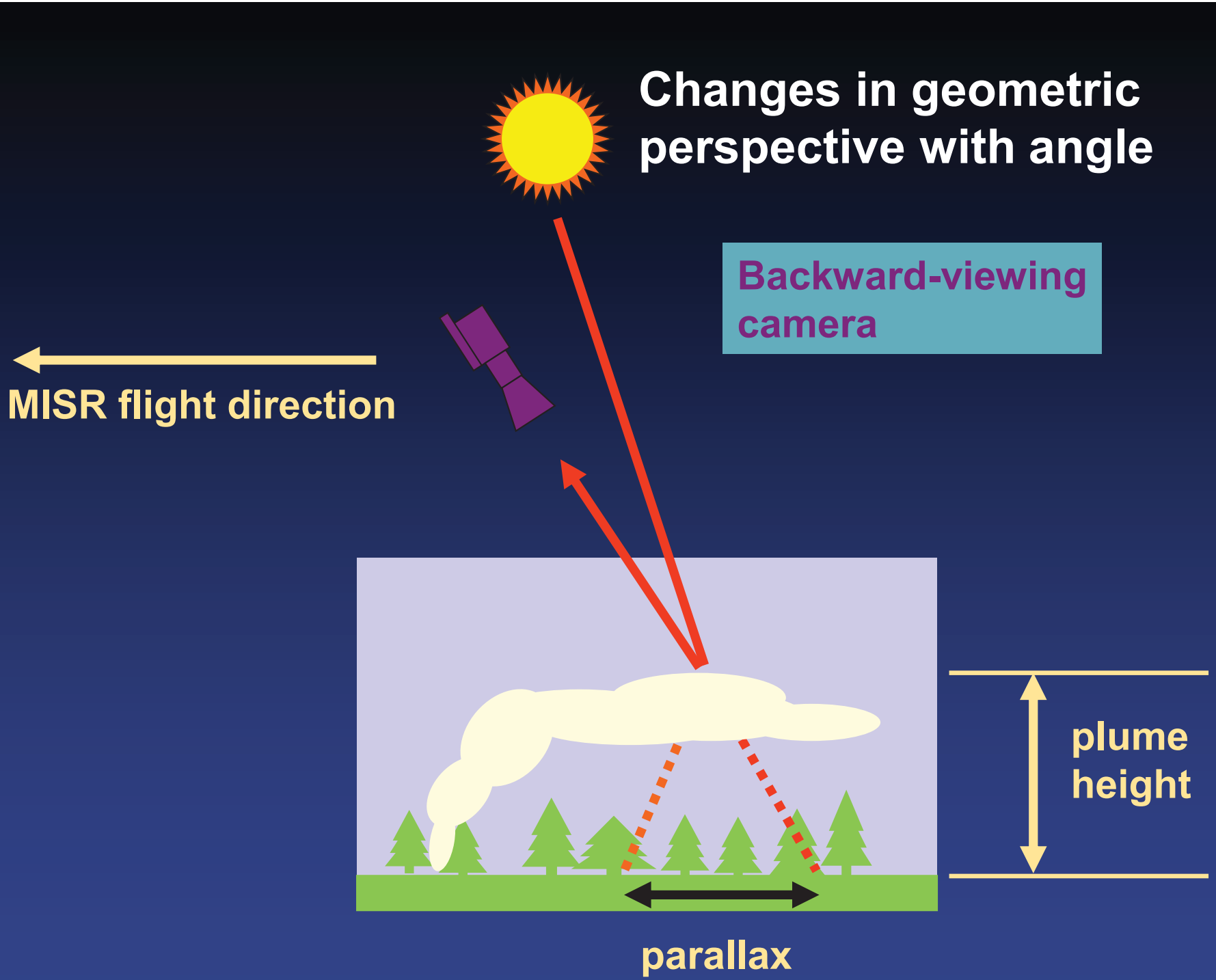


Different Techniques for *Assuming Model Source Strength*
Overestimate or ***Underestimate*** Observation
Systematically in Different Regions

Petrenko et al., JGR 2012


Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
plume height
apparent position

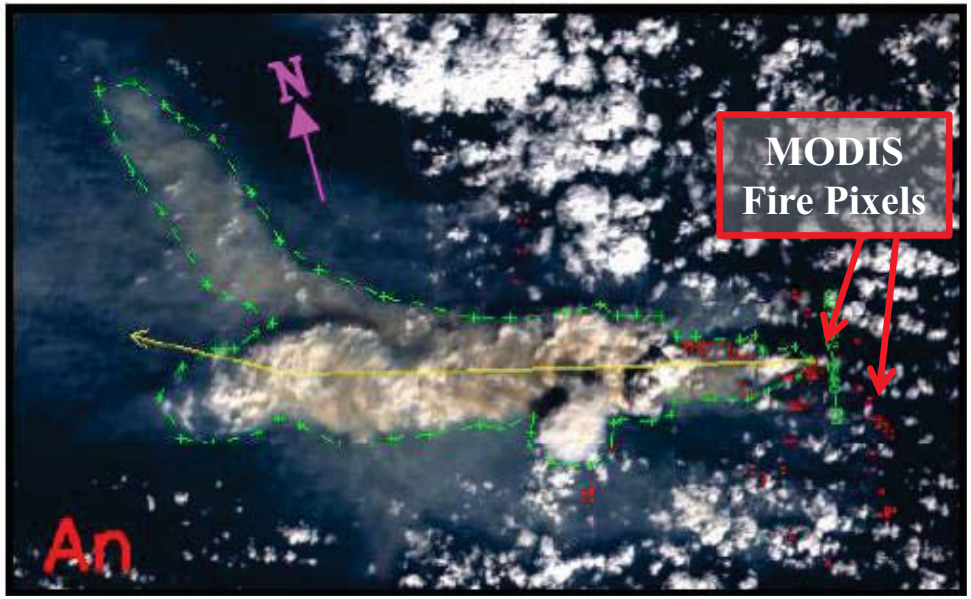
Diner et al.

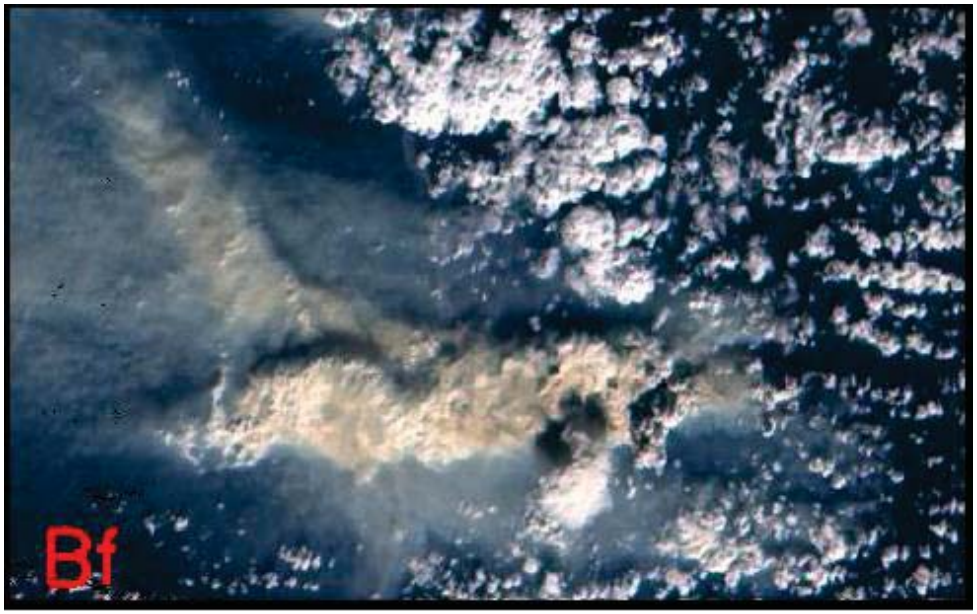

Changes in geometric perspective with angle
Backward-viewing camera
MISR flight direction
plume height
parallax

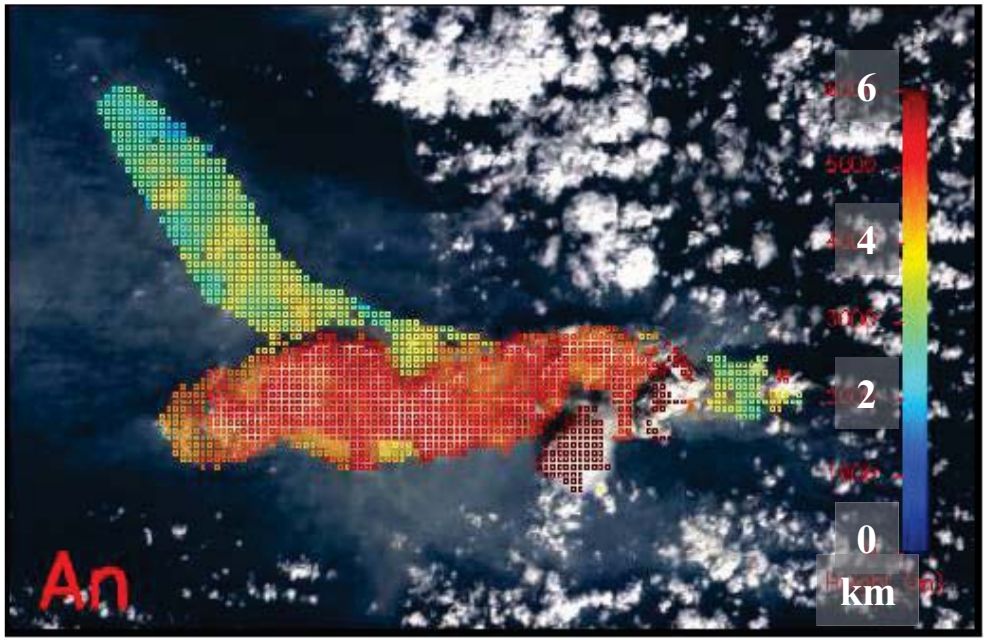
Diner et al.

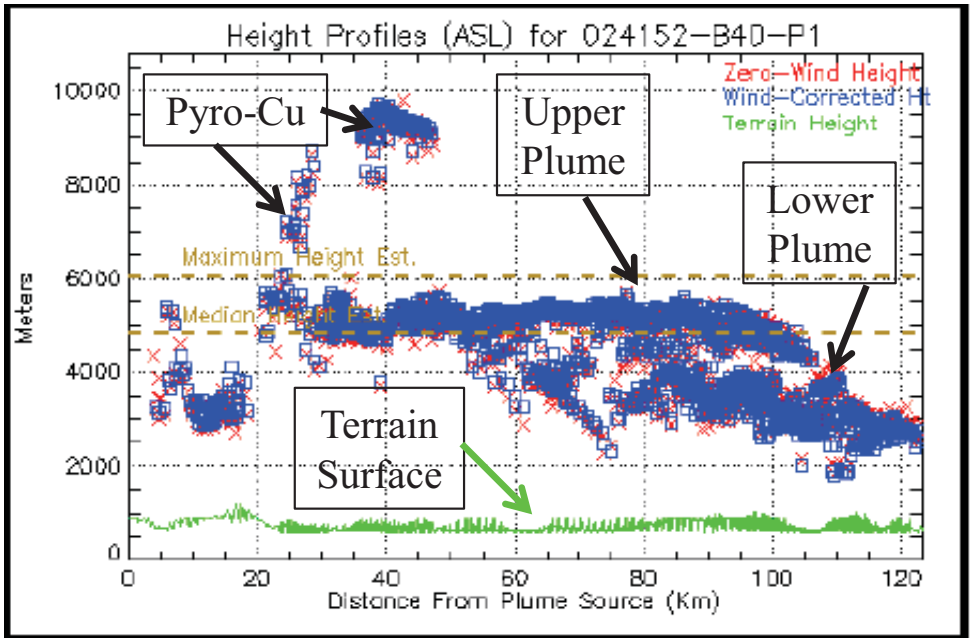
MISR *Smoke Plume Height* Mapping

July 2, 2004, Canada near Alaska border





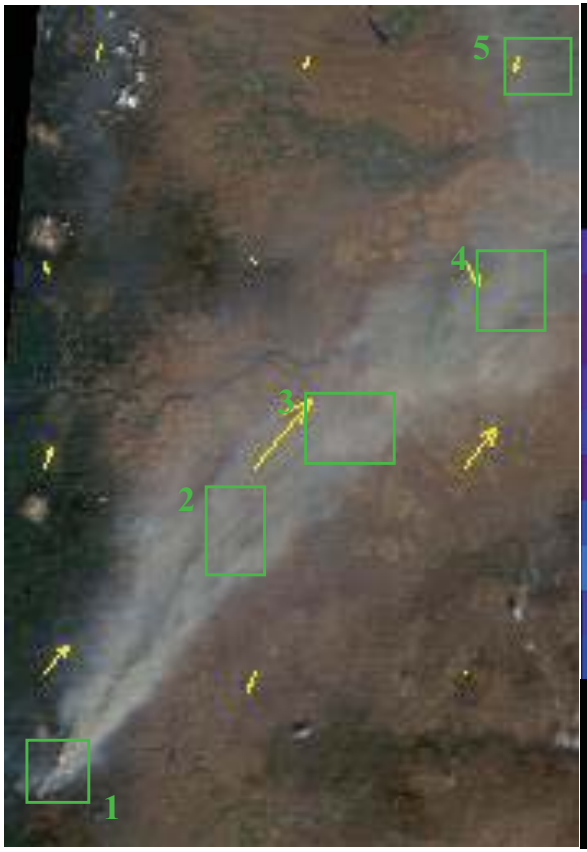


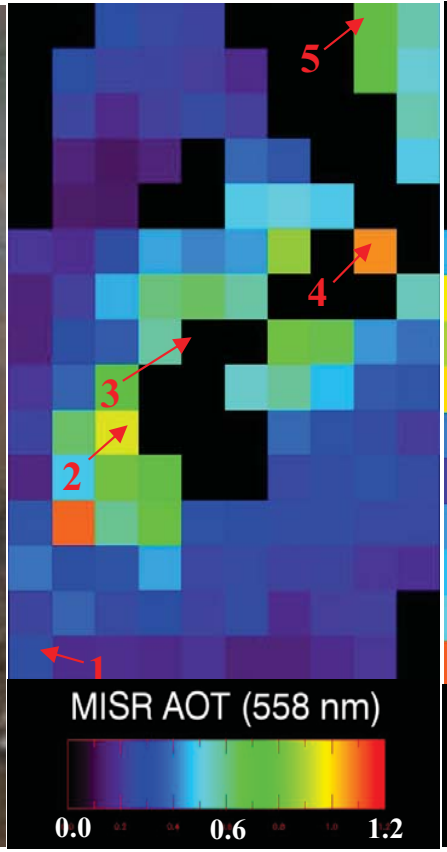


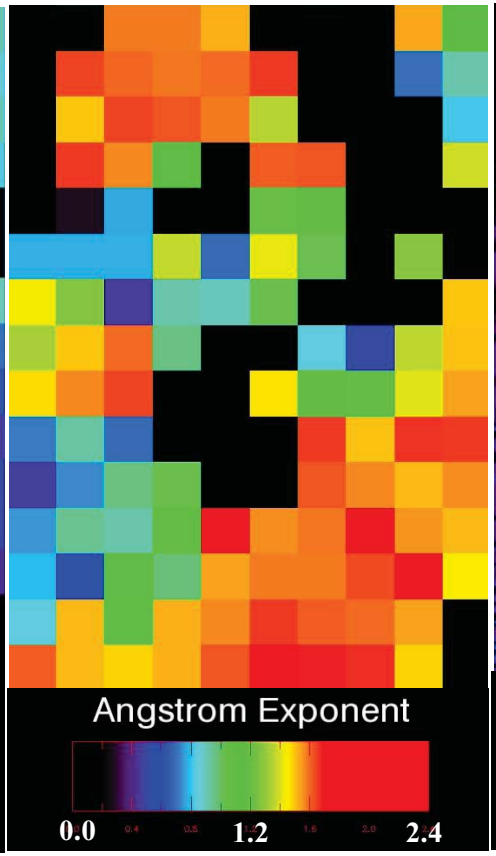
Nelson, et al., Proc. SPIE 2008

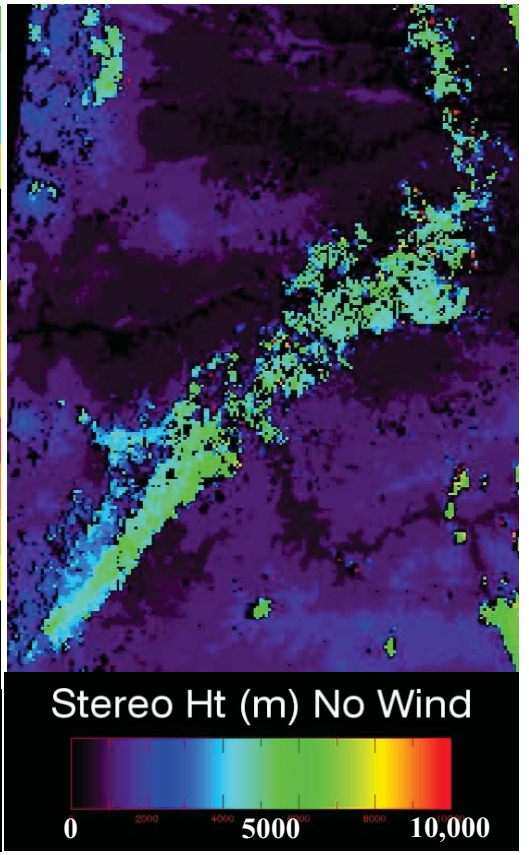
Oregon Fire Sept 04 2003

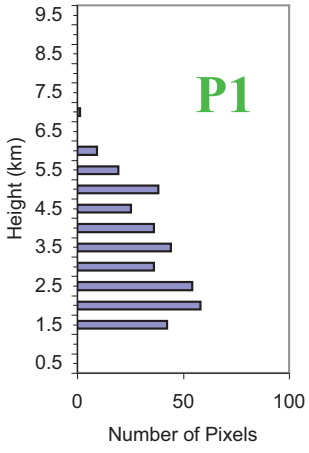
Orbit 19753 Blks 53-55 MISR Aerosols V17, Heights V13 (no winds)

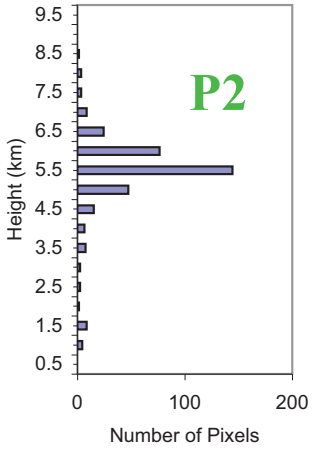


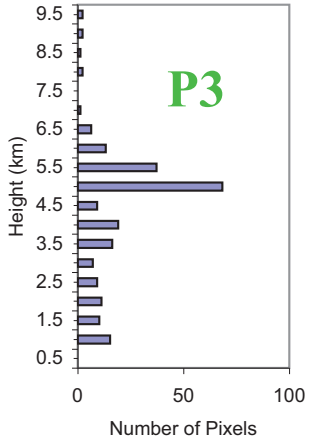


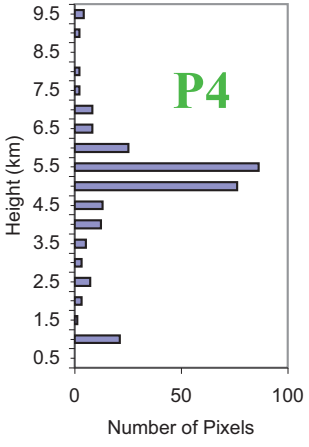


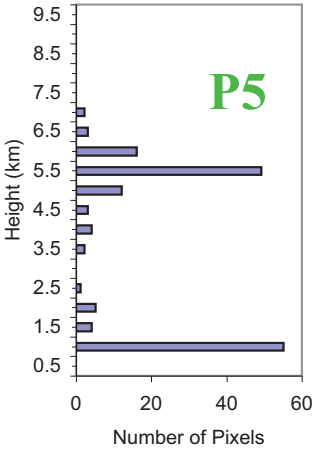


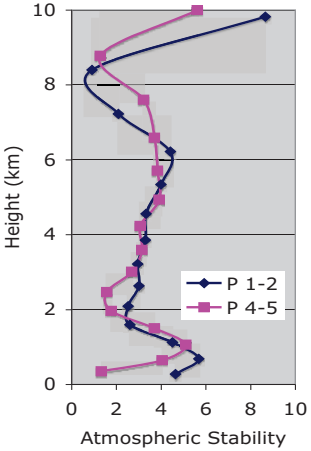








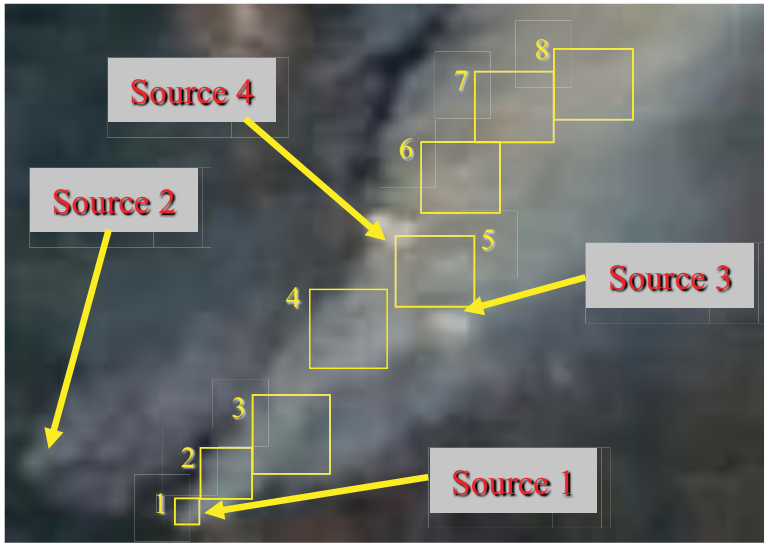




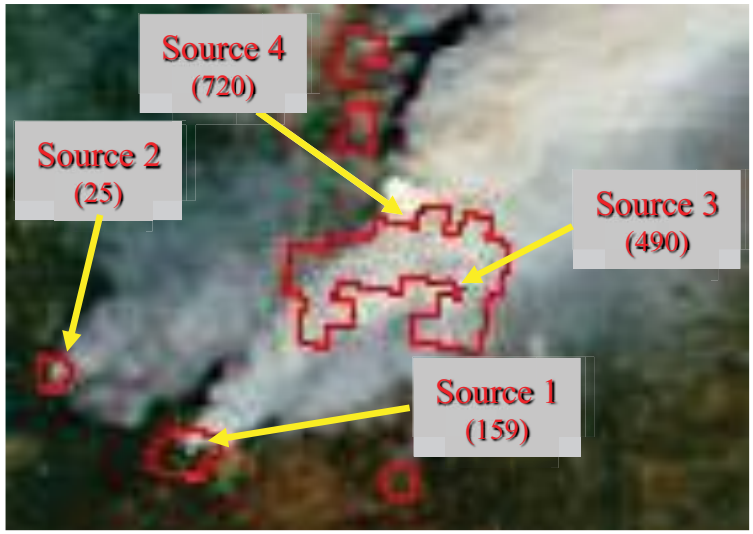
Kahn, et al., JGR 2007

Detail of Wildfire Source Region

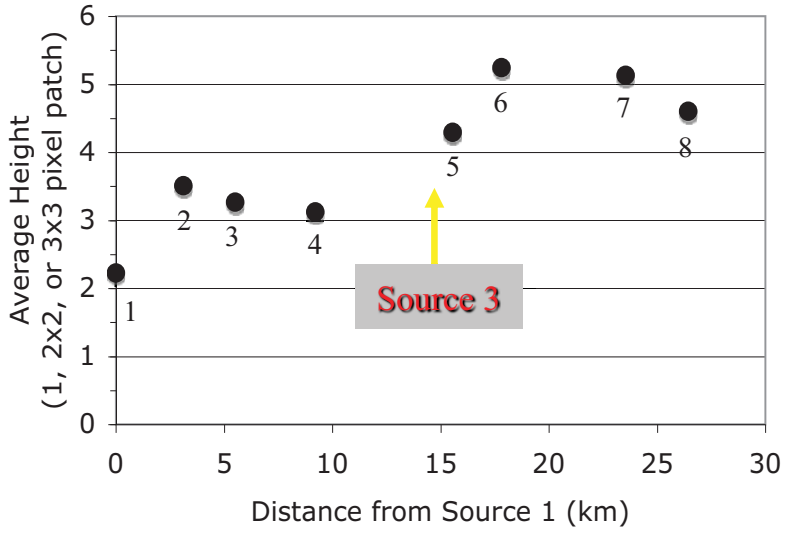
Oregon Fire Sept 04 2003



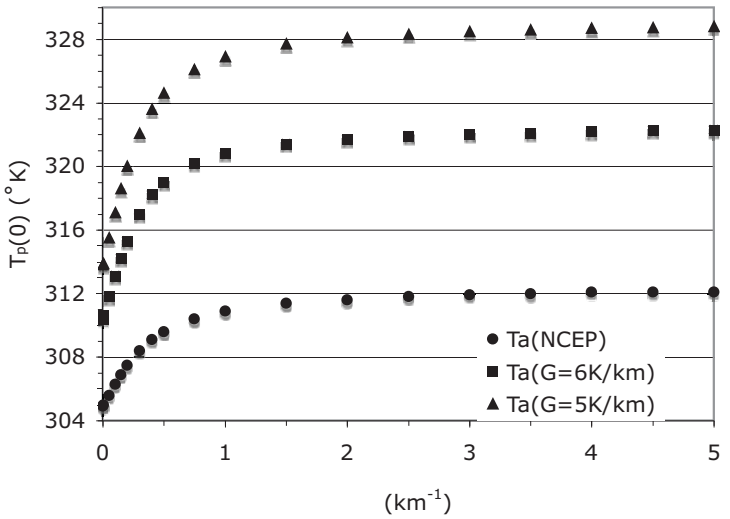
MISR Nadir **275 m** Image



MODIS Image + **Fire Power**



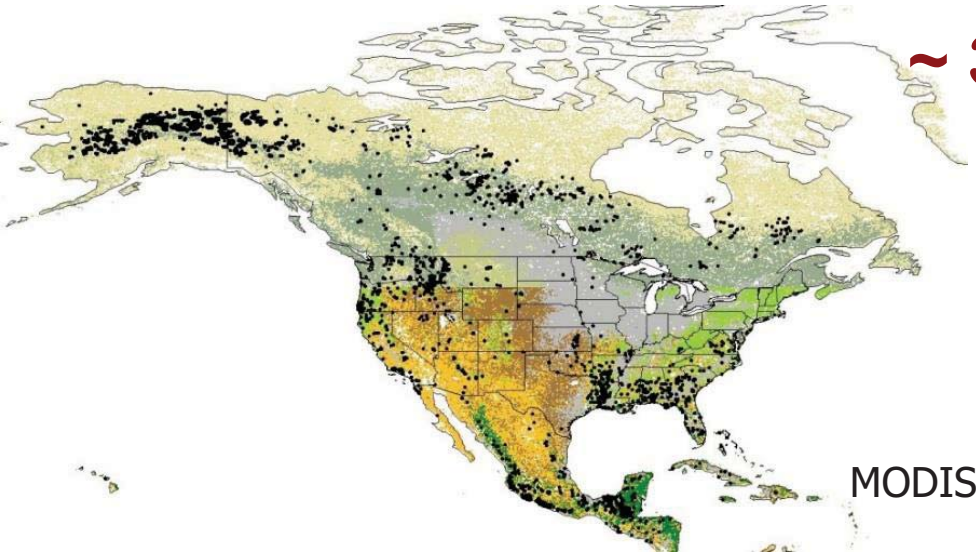
MISR **Plume Heights** for Sub-patches



Very Simple Plume Parcel Model

→ ***Broad swath + high spatial resolution*** needed to characterize sources

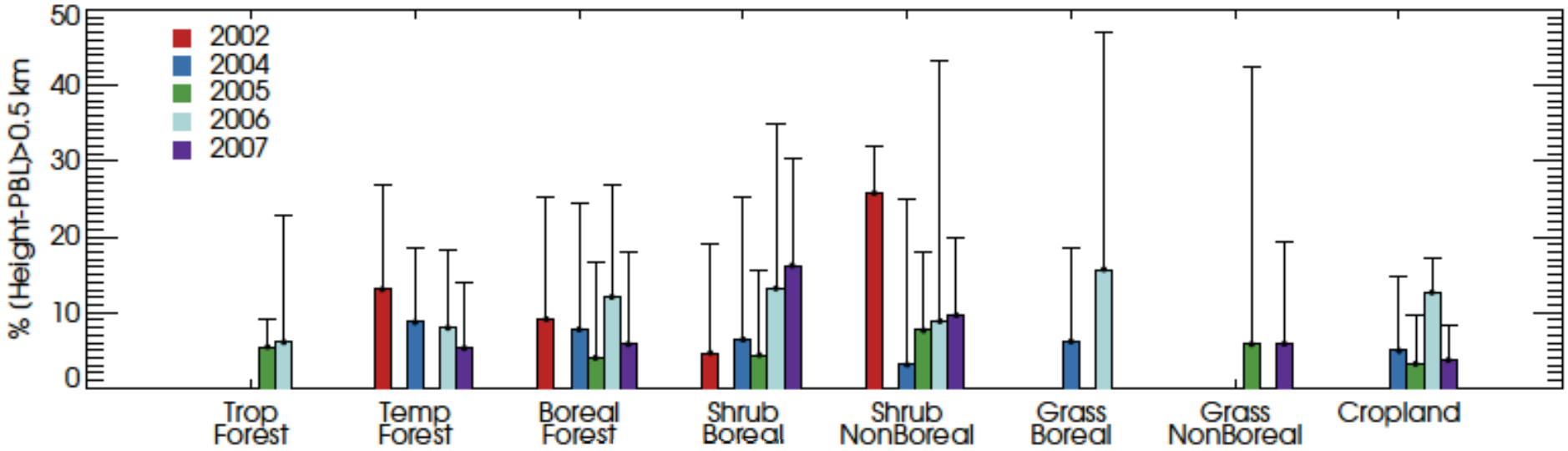
N. America Plume *Injection Height* Climatology



MODIS IGBP land cover map
(1x1 Km res)

~ 3400 plumes digitized over North America for 2002, 2004-2007

- Tropical Forest
- Temperate Forest
- Boreal Forest
- Boreal Shrubland
- Non-Boreal Shrubland
- Boreal Grassland
- Non-Boreal Grassland
- Cropland



Percent of plumes >0.5 km ***above BL***, stratified by year and vegetation type

Val Martin et al. ACP 2010

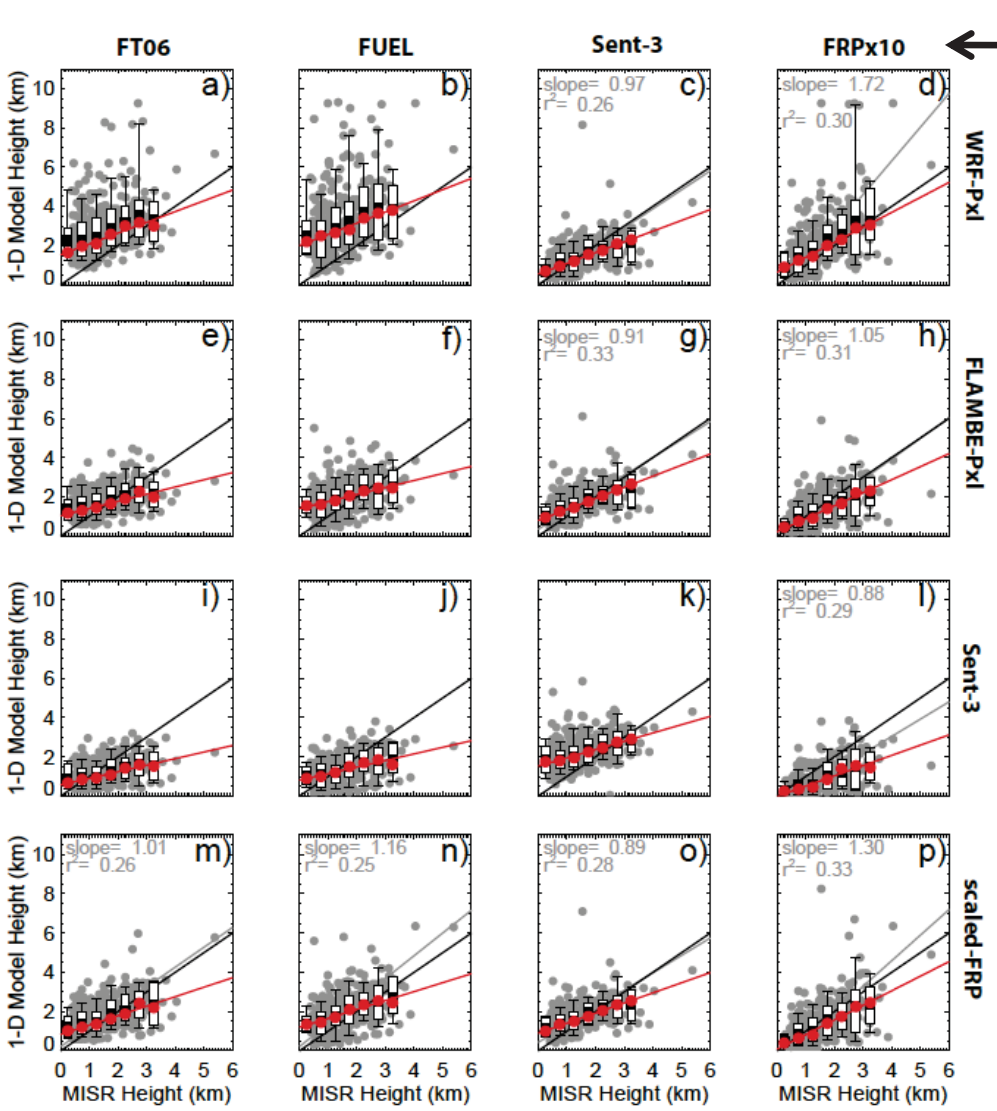
Evaluation of a 1D plume-rise model: Towards a parameterization of smoke *injection heights*

To Constrain models:

Need to assess the

Parameterizations

actually used

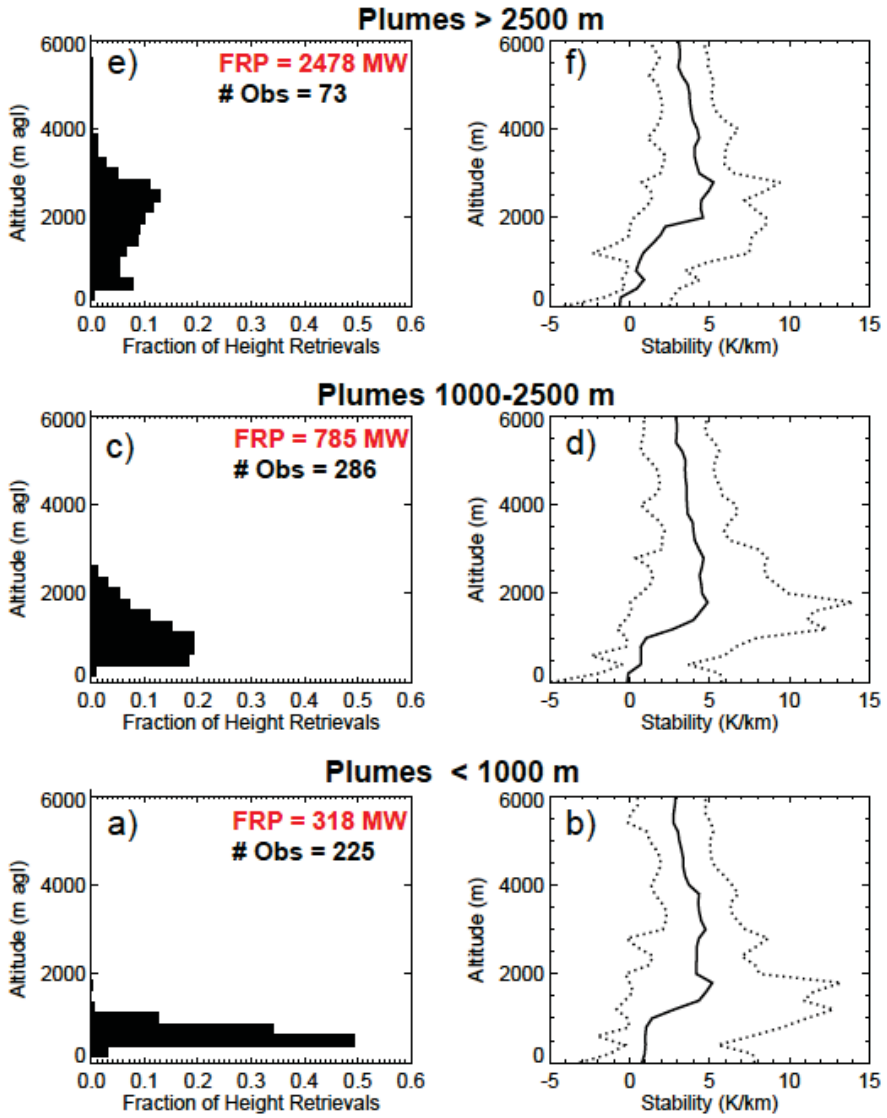


1-D Plume-rise model heights vs. **MISR-observed max. plume heights**

-- Plume-rise calculations have ***lower dynamic range than observed***, but very variable

Val Martin et al., JGR 2012

Evaluation of a 1D plume-rise model: Towards a parameterization of smoke *injection heights*



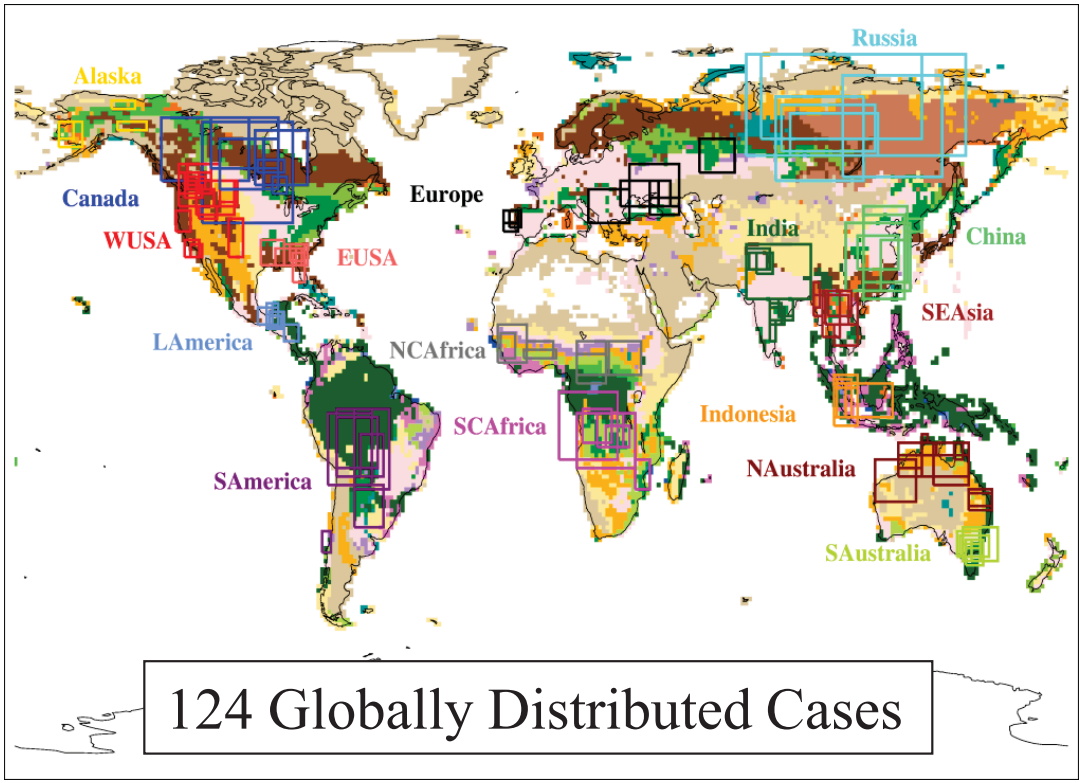
The key factors:

- ***Fire Energy***
  (fire area; heat flux, FRP)
- ***Atmospheric Stability***
- ***Entrainment***

Plume height increases systematically as ***FRP*** increases and ***Atmospheric Stability*** decreases

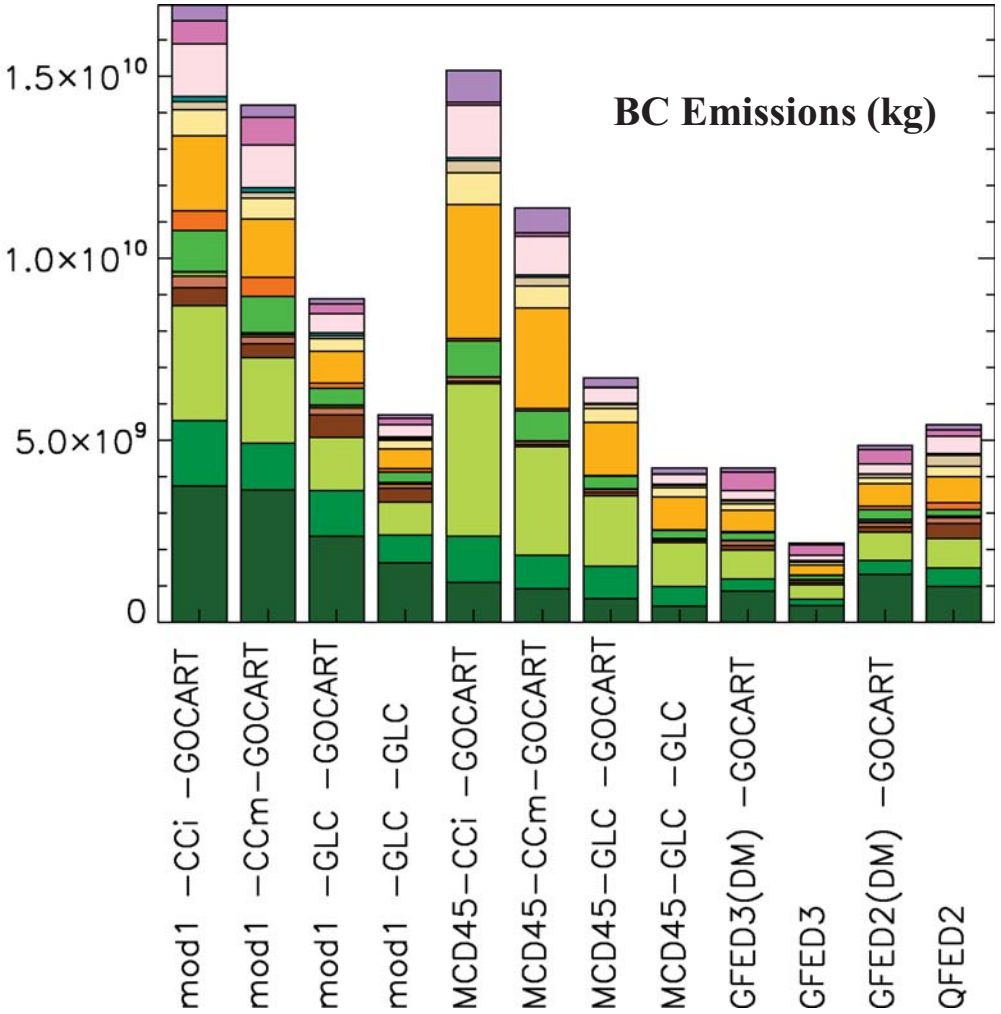
Val Martin et al., JGR 2012

Satellite AOD snapshots to constrain Biomass Burning Emissions *Source Strength*



124 Globally Distributed Cases

1 Tree cover, broadleaved, evergreen
2 Tree cover, broadleaved, deciduous, closed
3 Tree cover, broadleaved, open
4 Tree cover, needle-leaved, evergreen
5 Tree cover, needle-leaved, deciduous
6 Tree cover mixed leaf type
7 Tree cover, regularly flooded, fresh water
8 Tree cover, regularly flooded, saline water
9 Mosaic: tree cover / other natural vegetation
10 Undefined
11 Shrub cover, closed-open, evergreen
12 Shrub cover, closed-open, deciduous
13 Herbaceous cover, closed-open
14 Sparse herbaceous or sparse shrub cover
15 Regularly flooded shrub and/or herbaceous cover
16 Cultivated and managed areas
17 Mosaic:Cropland/Tree cover/other natural veg
18 Cropland/Shrub and/or grass cover

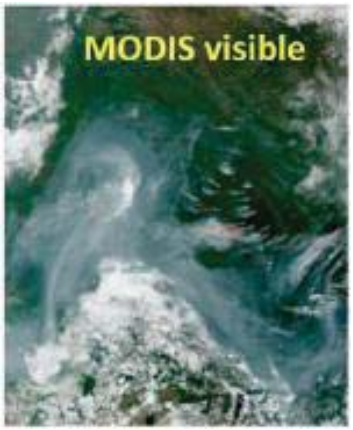


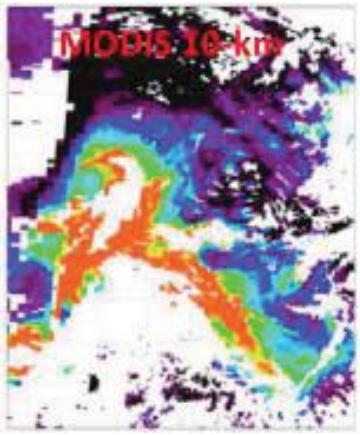
13 Smoke Emission Estimates

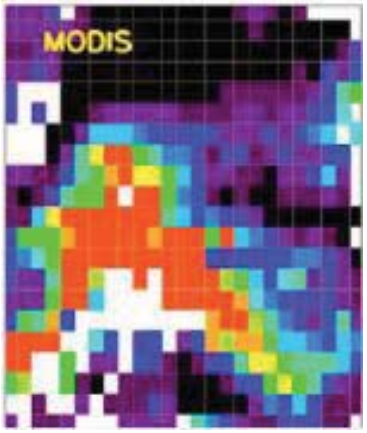
Petrenko, Kahn, Chin, et al., JGR 2012

MODIS-GoCART Total Column AOD Comparisons

Sample Case: Siberia July 20 2006







Goddard Chemistry Aerosol Radiation and Transport (GOCART) model runs

3-hourly output

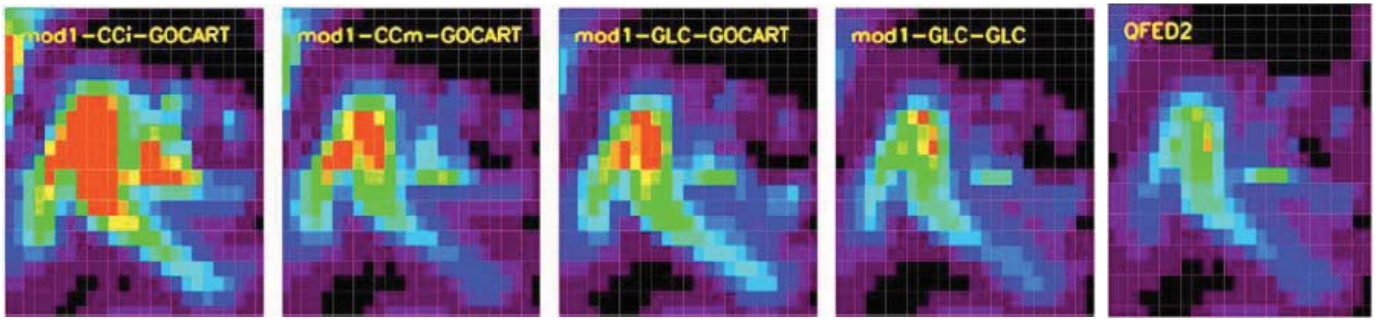
Resolution: 1°(lat) x 1.25°(lon) x 30 vert. layers

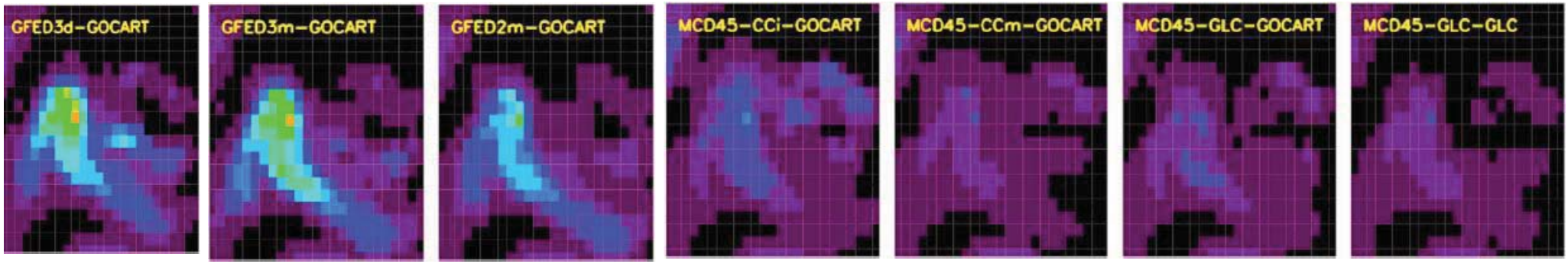
Meteorological fields GEOS DAS Version 4

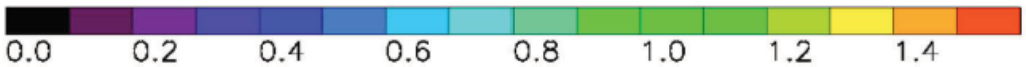
Emissions include: dust, sea salt, anthropogenic, sulfate & precursors, BB

13 BB emission options in separate model runs

Study period: June 2006-June 2007





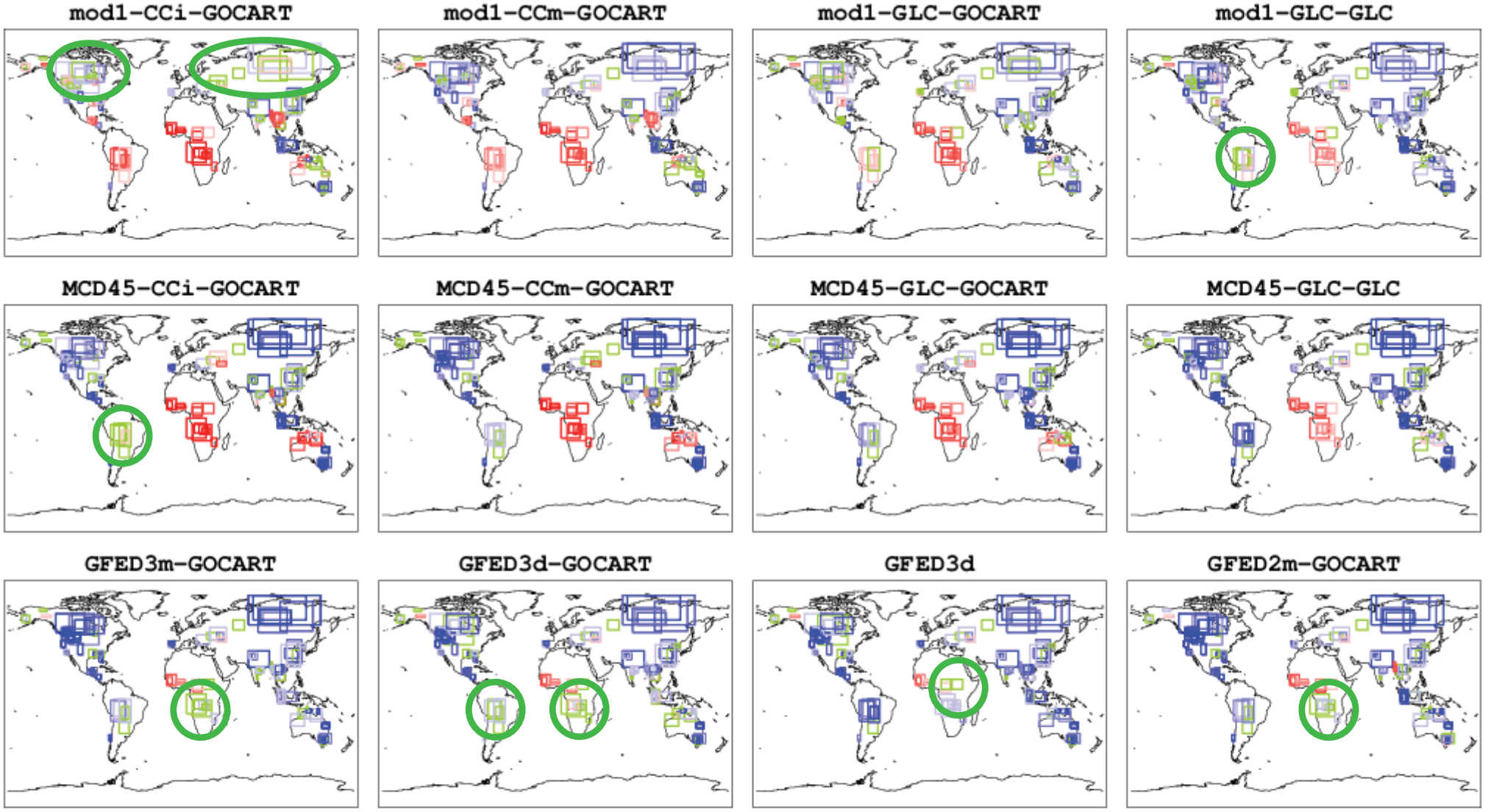


AOD (550nm)

Petrenko et al., JGR, 2012

Ratio of GOCART to MODIS average AOD

For each case, for 12 emission estimates



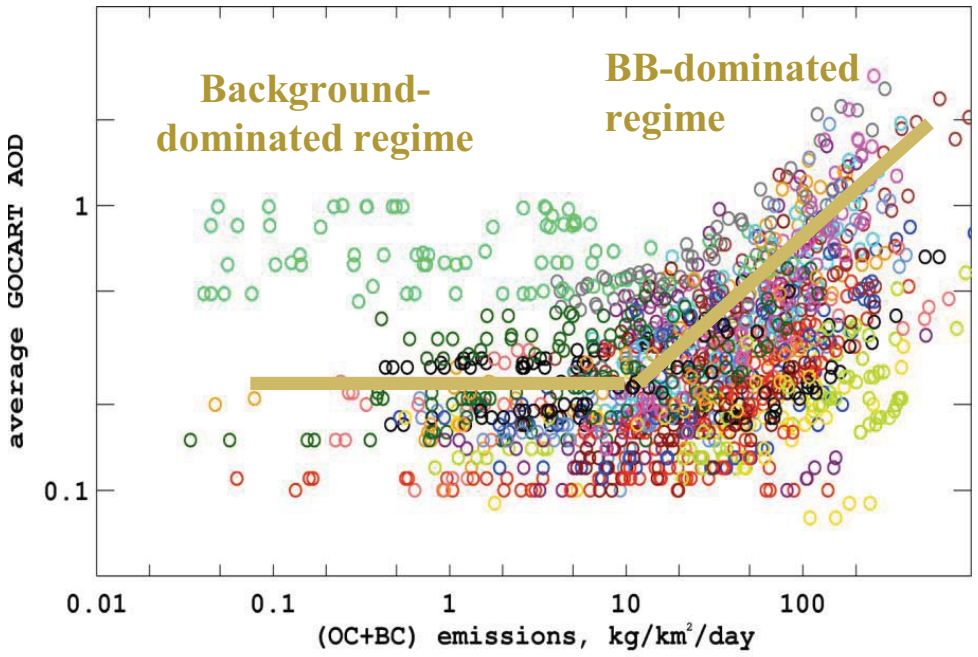
Systematic regional patterns; some emissions work better in certain regions

Quantitative Relationship Between Smoke Emission and AOD

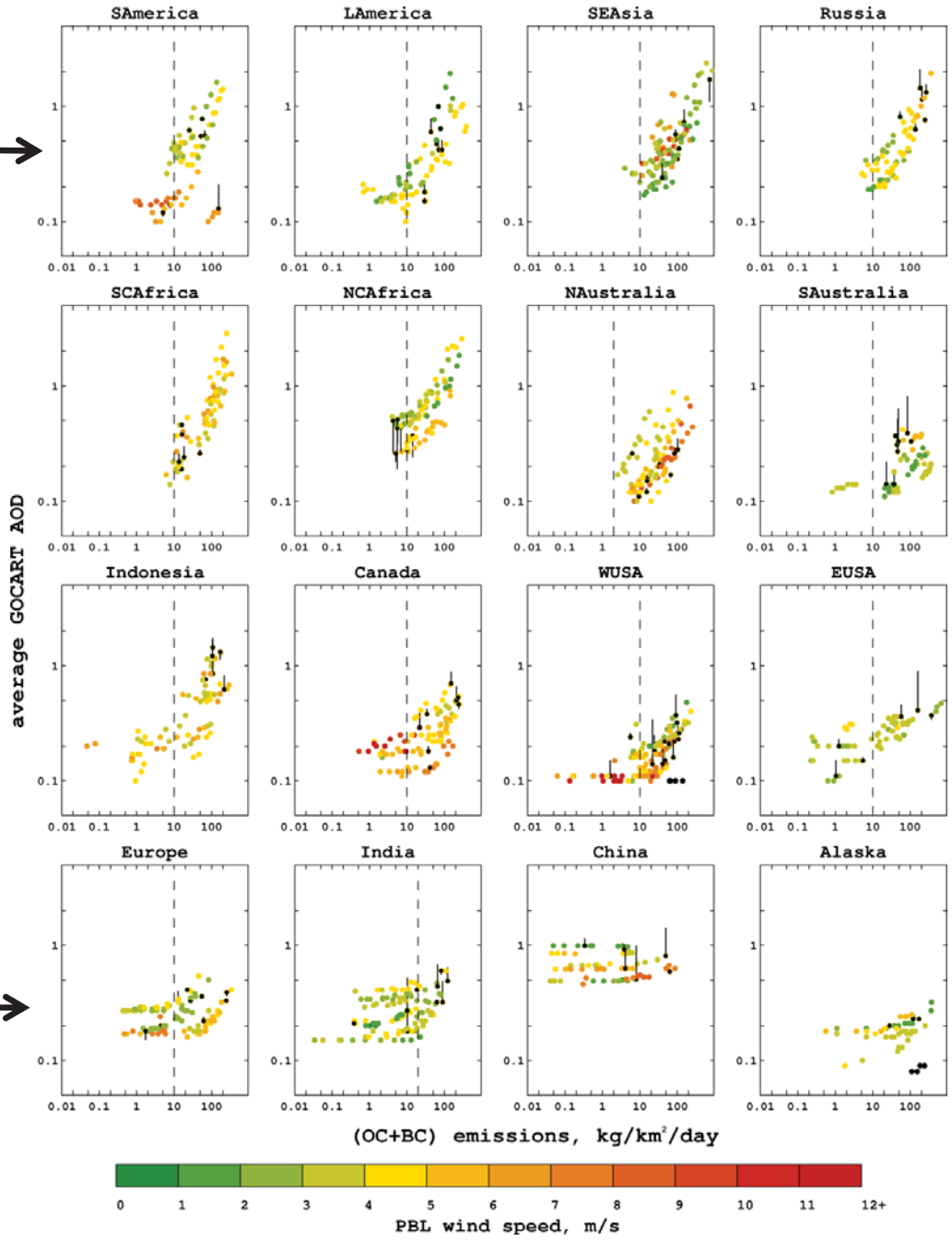
Depends On

- ***Wind Speed at source***
- ***Background AOD***

Steeper slope ~
Lower wind speed →



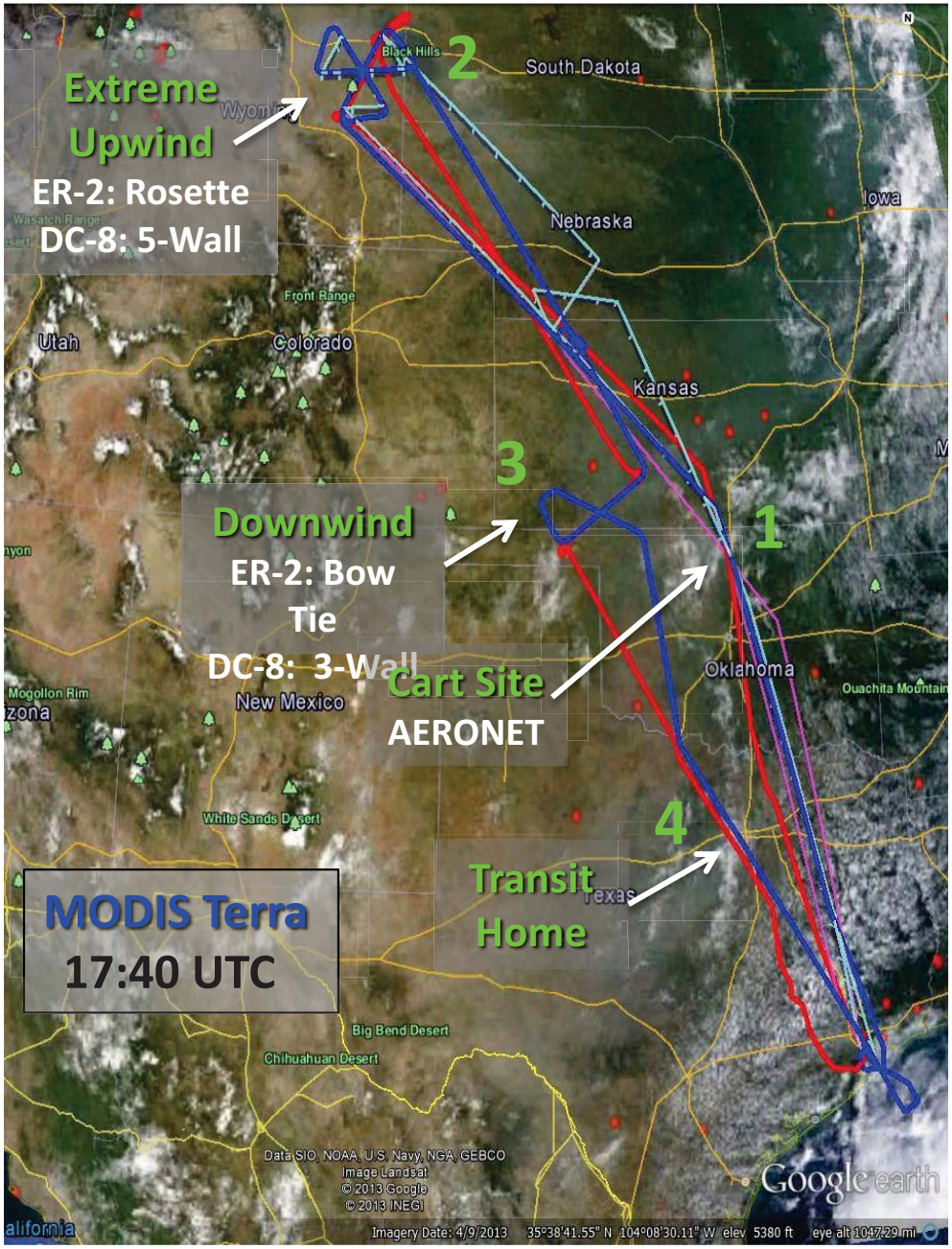
High background AOD ~
Smoke plume insignificant →

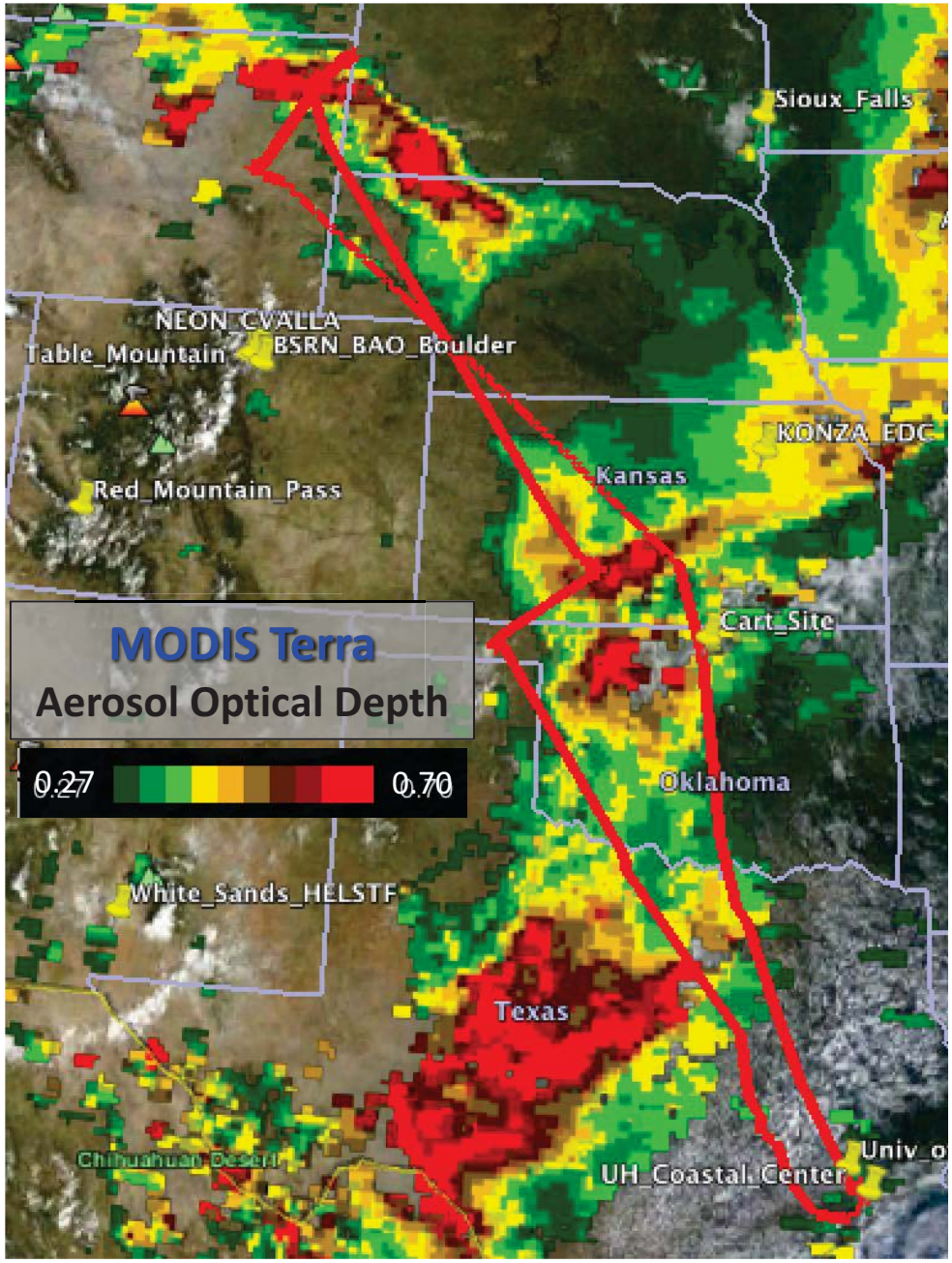


Petrenko et al., JGR 2012

SEAC4RS Field Campaign

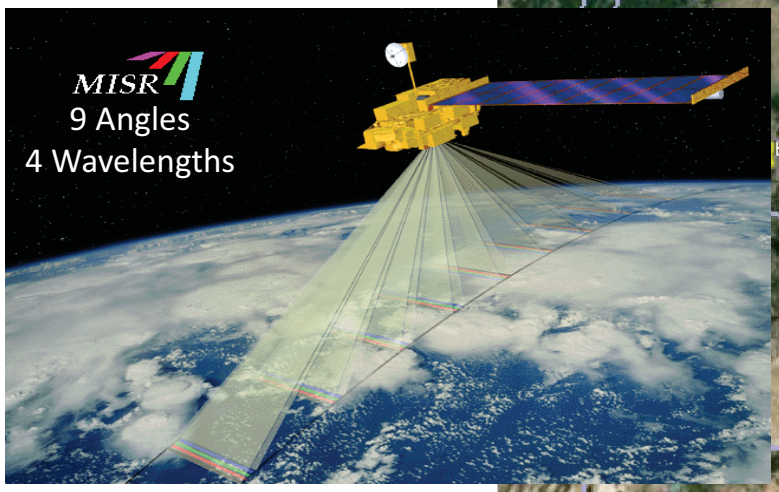
DC-8 and ER-2 Flights Monday, 19 August 2013

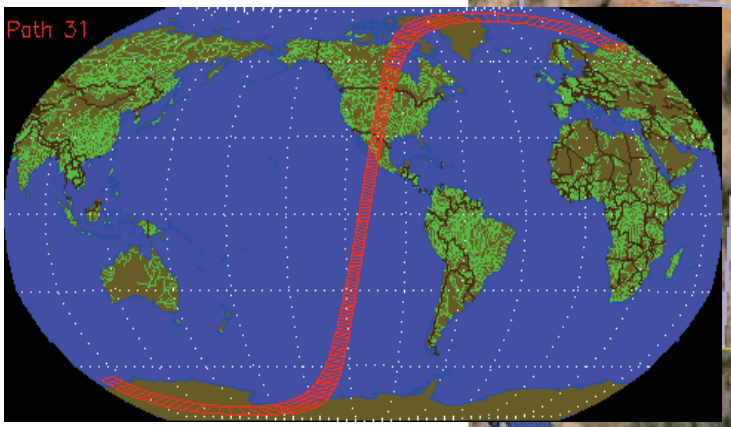


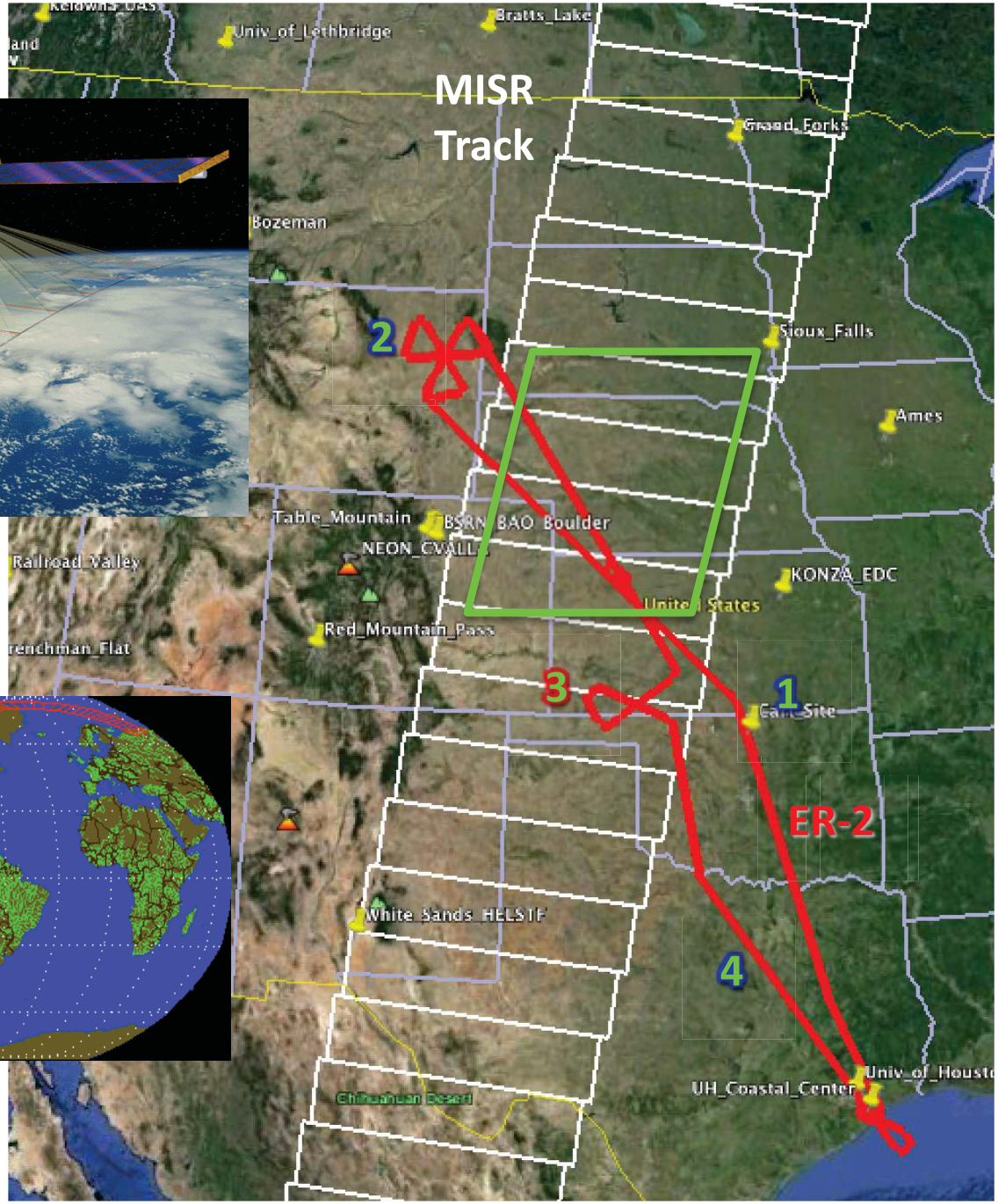


MISR (Multi-angle Imaging SpectroRadiometer) Overpass

Monday, 19 August 2013 17:40 UTC







17:40 UTC
Path 031
Orbit 72716

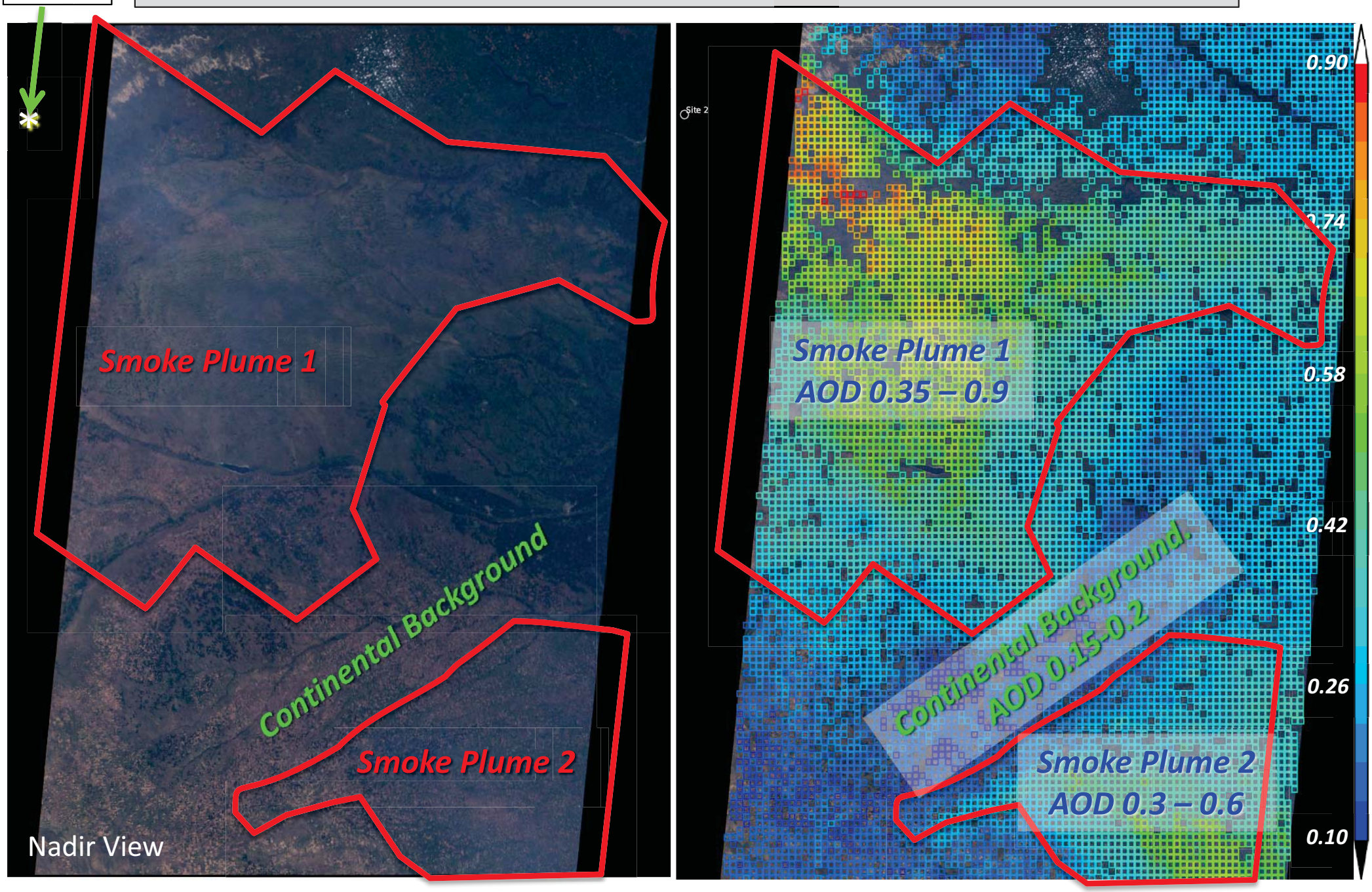
South Dakota

Nebraska

Kansas

MISR Aerosol Optical Depth (Research Algorithm)

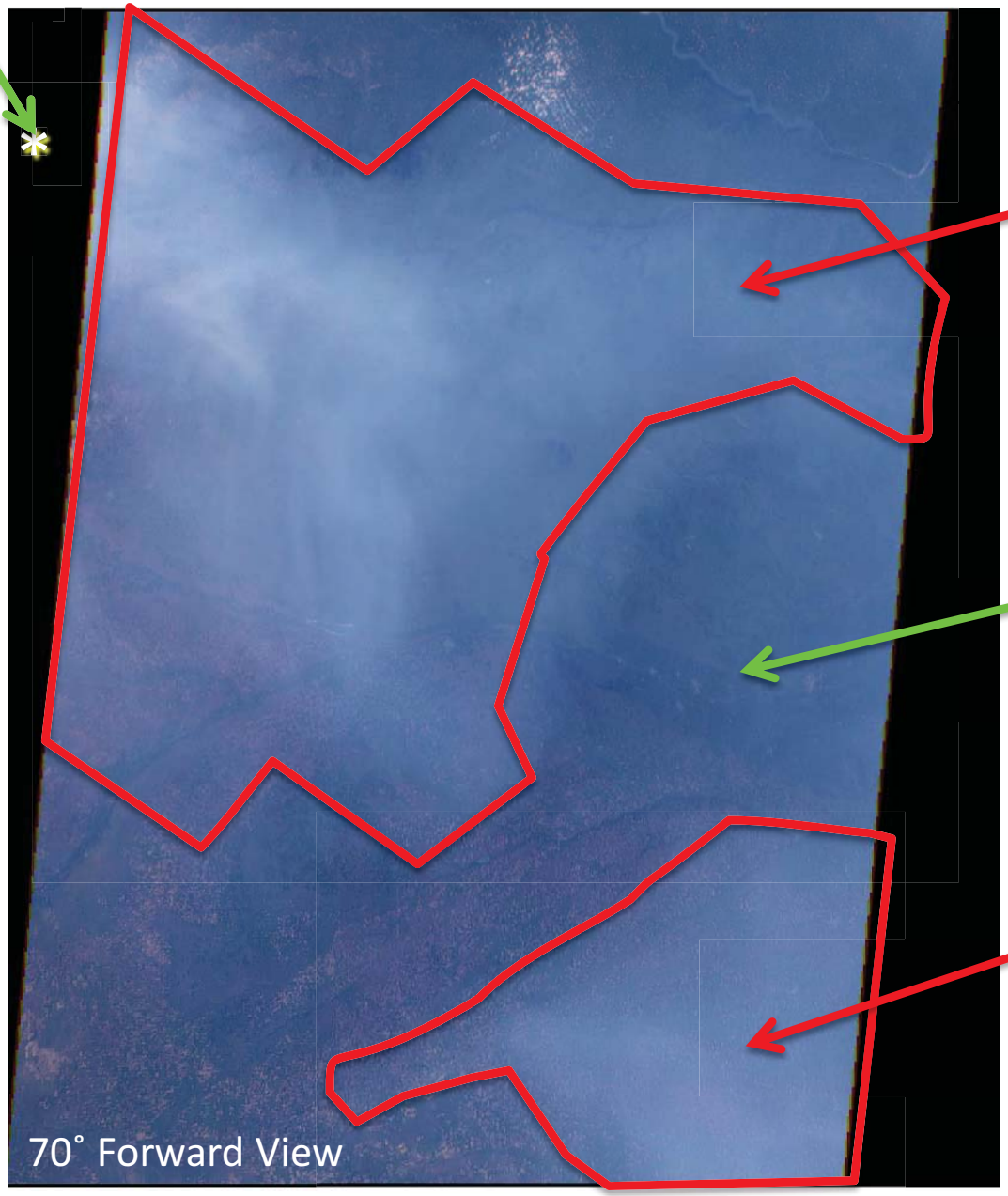
19 August 2013



MISR Aerosol Type (Research Algorithm)

19 August 2013

Site 2



Smoke Plume 1
AOD 0.35-0.9
*ANG 1.5-1.9 (**small**)*
*SSA 0.94-0.98 (**absorbing**)*
*FrNon-Sph 0-0.2 (**mostly spherical**)*

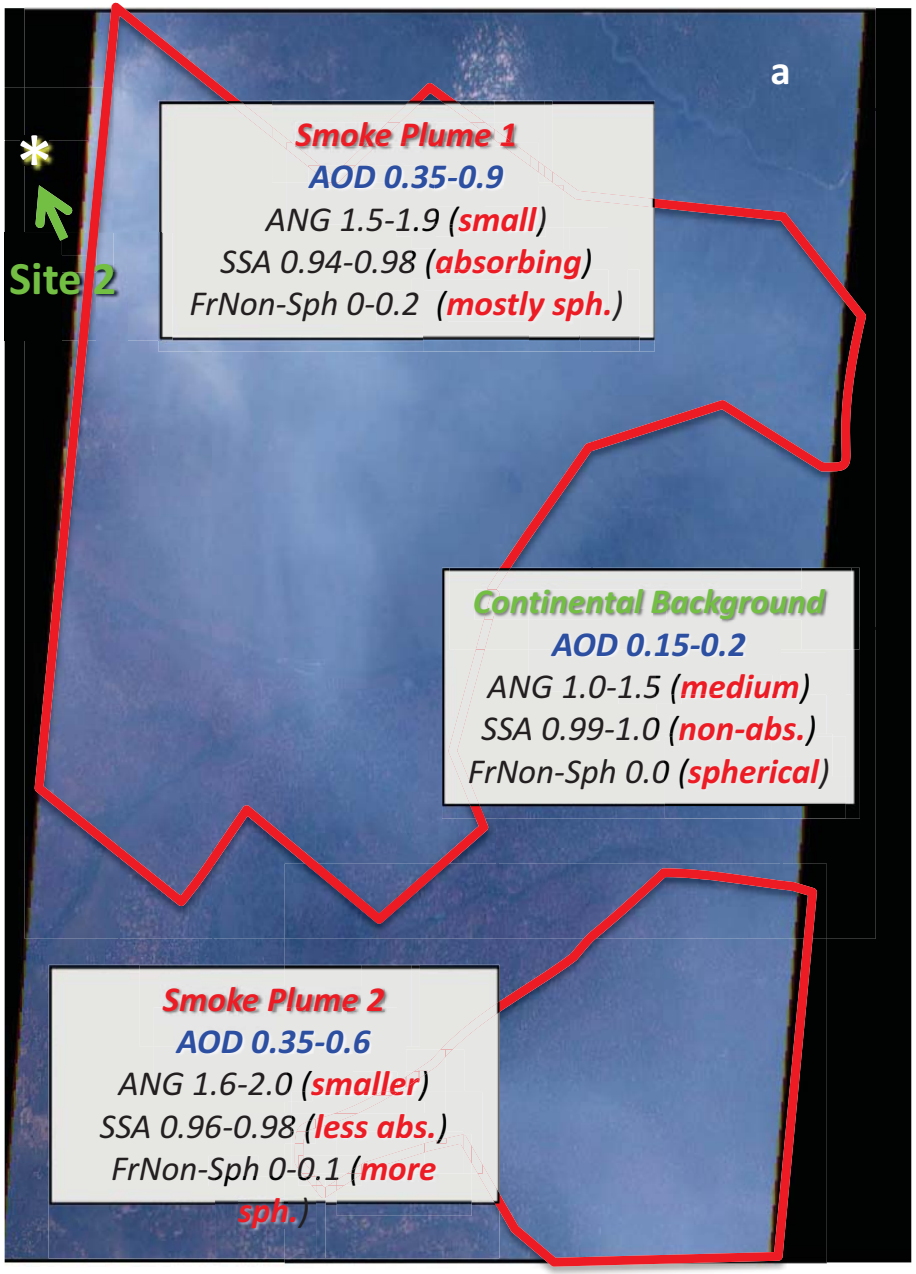
Continental Background
AOD 0.15-0.2
*ANG 1.0-1.5 (**medium**)*
*SSA 0.99-1.0 (**non-absorbing**)*
*FrNon-Sph 0.0 (**spherical**)*

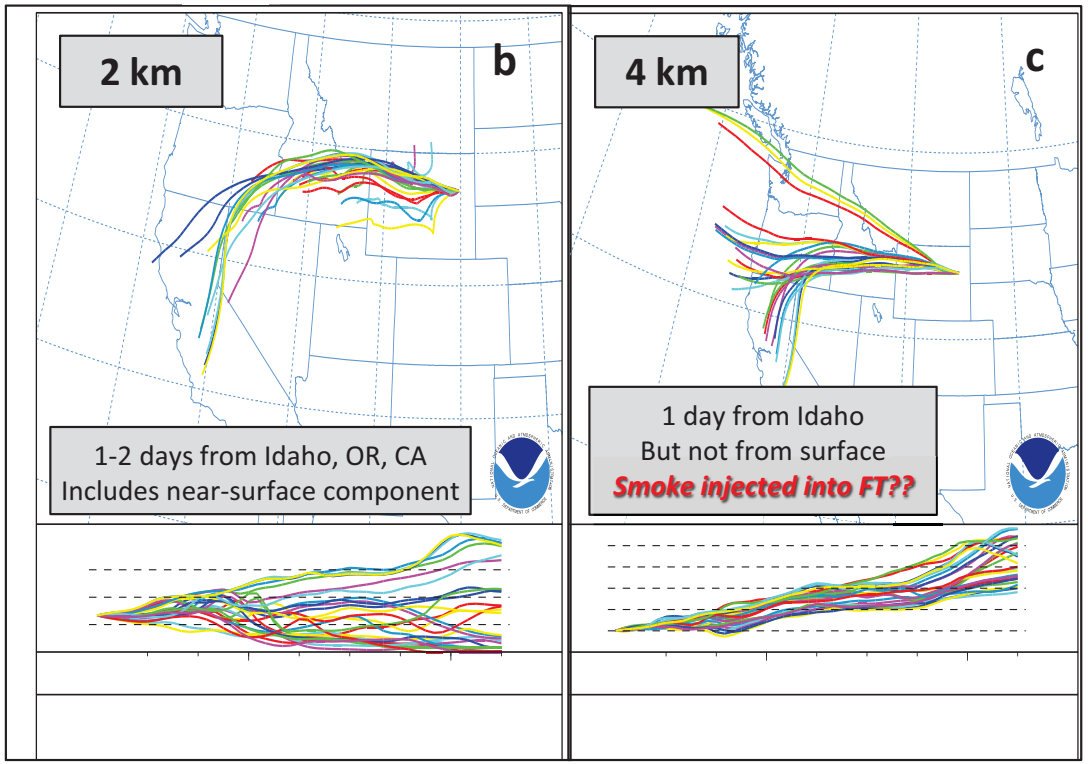
Smoke Plume 2
AOD 0.35-0.6
*ANG 1.6-2.0 (**smaller**)*
*SSA 0.96-0.98 (**less absorbing**)*
*FrNon-Sph 0-0.1 (**more spherical**)*

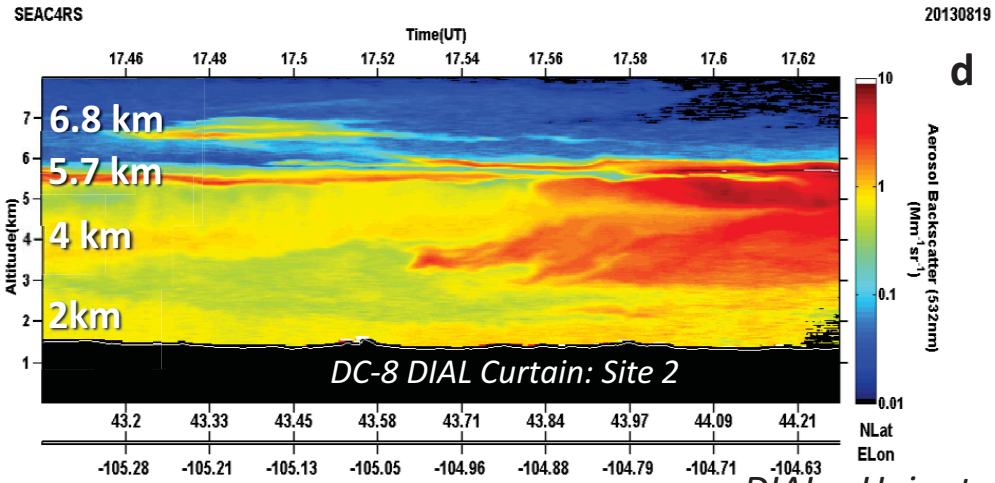
Passive-remote-sensing ***Aerosol Type*** is a ***Total-Column-Effective***, ***Categorical*** variable!!

Site 2 Smoke Transports

19 August 2013



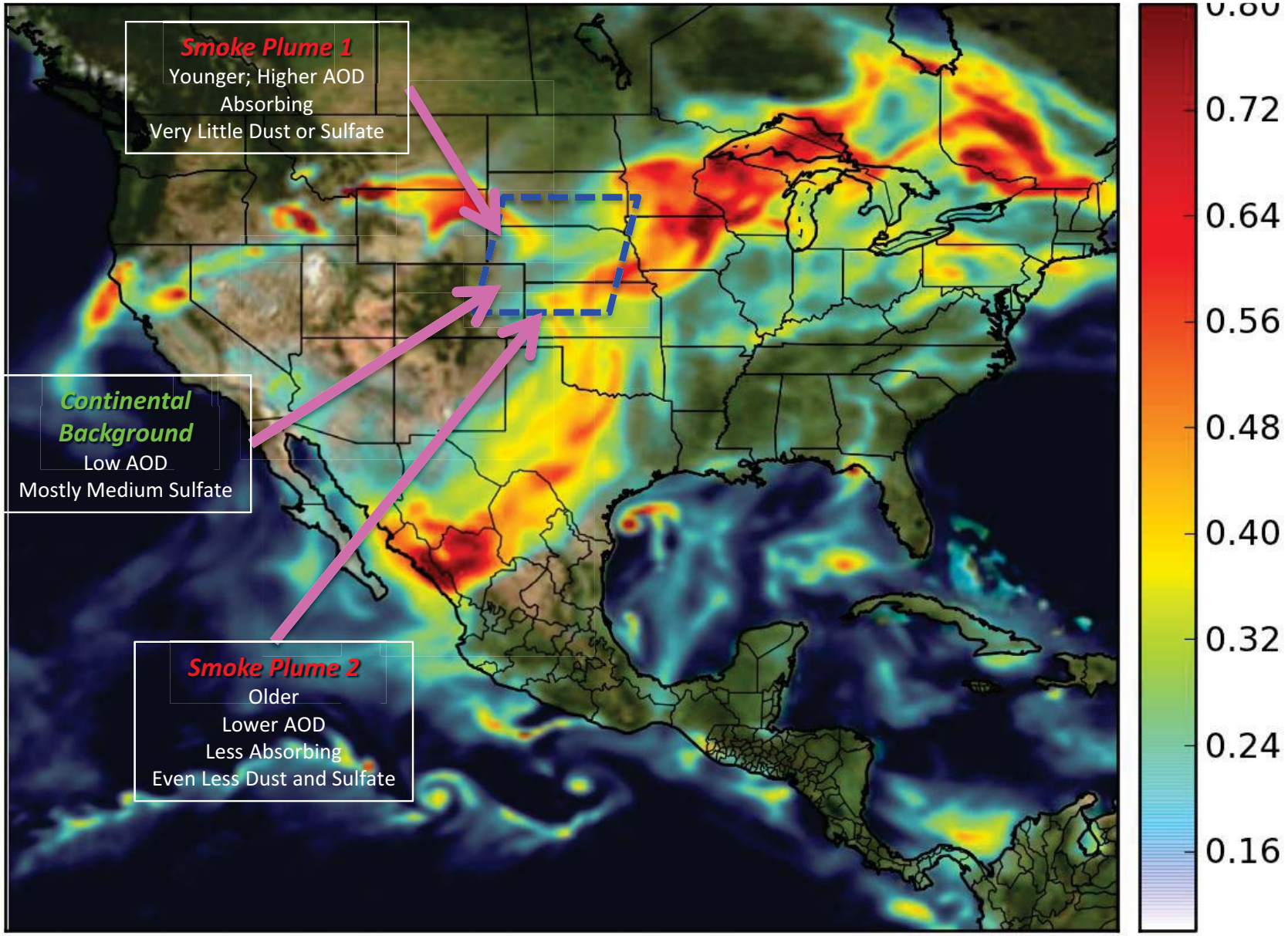




DIAL – Hair et al.

GEOS-5 MODEL Aerosol Optical Depth

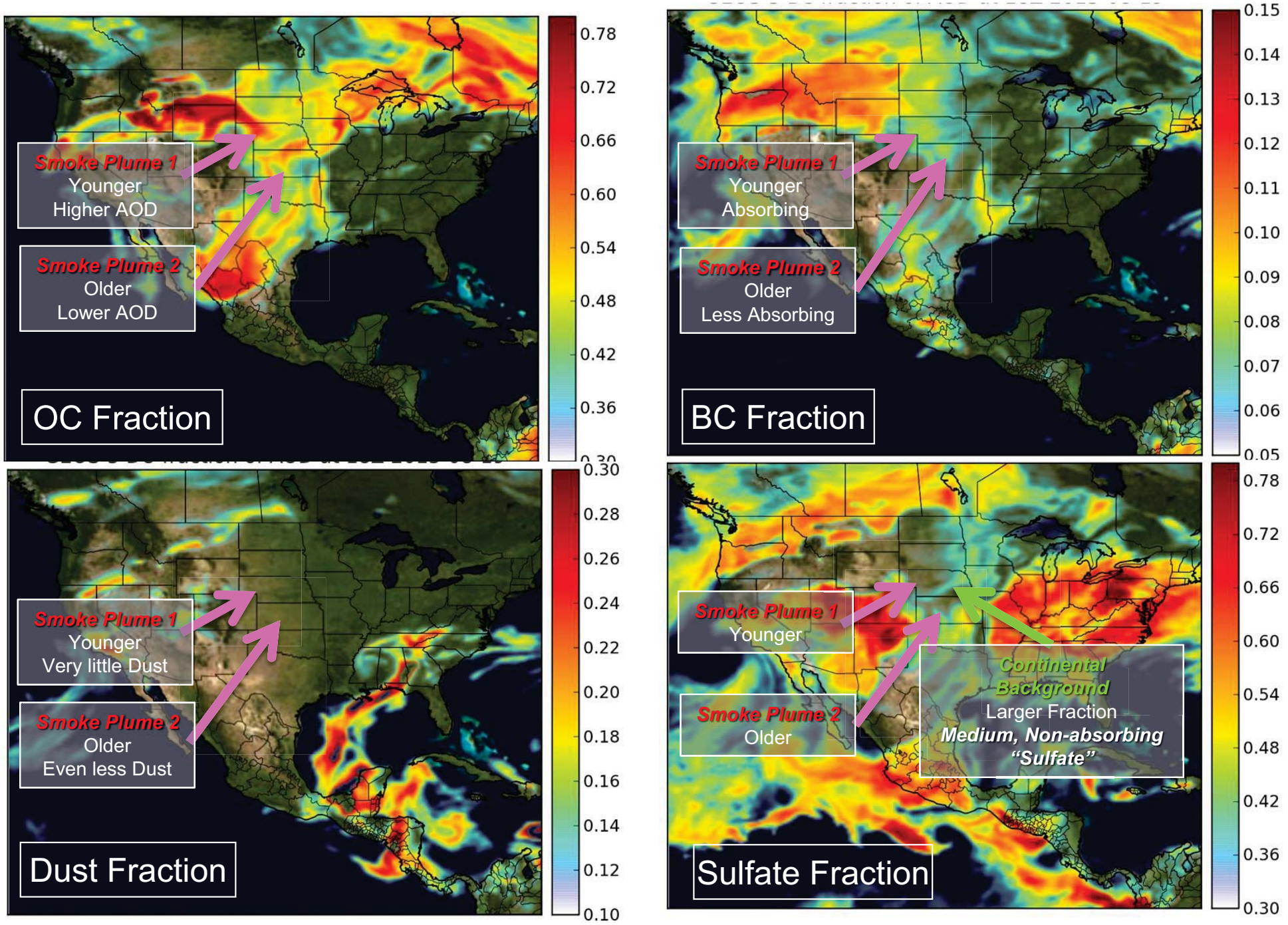
19 August 2013 18 UTC



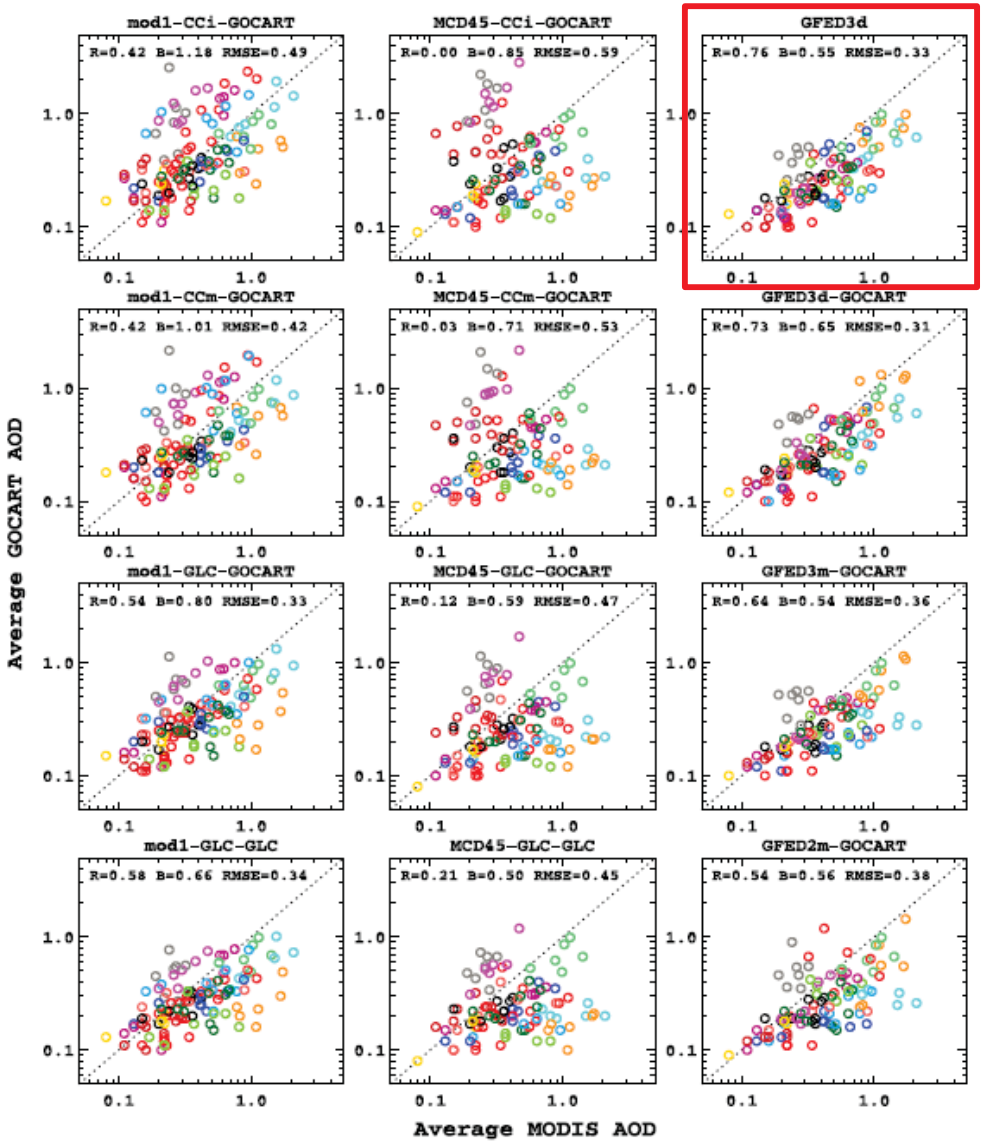
GEOS-5 Team – DaSilva & Randles

GEOS-5 MODEL Aerosol Type

19 August 2013 18 UTC



AeroCom BB Experiment AOD – *Motivation*



- We have a substantial set of ***satellite wildfire plume AOD snapshots and injection heights*** to help calibrate model/inventory performance
- We are: (1) adding ***more fire source-strength cases***, (2) using MISR to ***improve the AOD constraints*** and (3) adding ***2008 global injection heights***
- We selected ***GFED3-daily*** due to good overall source strength performance, but ***any inventory can be tested***
- Joint effort, to ***test multiple, global models*** to draw robust BB injection height & emission strength conclusions

We provide: Satellite-based injection height and smoke plume AOD climatologies

Experiment Design

	Exp.	BB Daily emission	Injection height
	BB0	***No BB emission***	
Control →	**BB1**	**GFED v3**	Boundary layer
	BB2	**GFED v3 x 0.5**	Boundary layer
	BB3	**GFED v3 x 2**	Boundary layer
	BB4	**GFED v3 x 5**	Boundary layer
Stage 2 →	BB5	**GFED v3**	From MISR plume ht.
	BB6	**GFED v3 x 5**	From MISR plume ht.

Requested output:

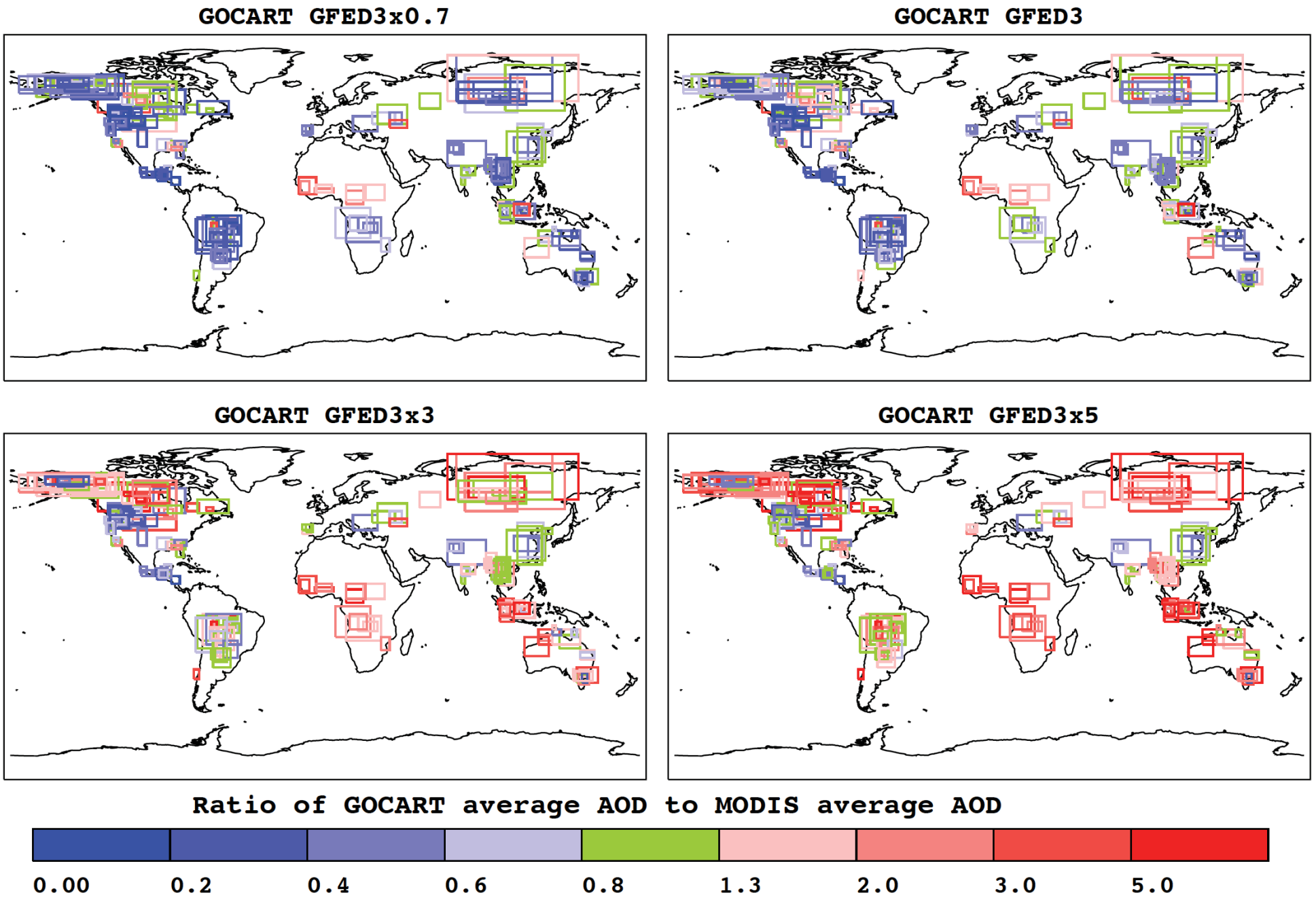
2-D, 3-hourly, instantaneous

- Total column ***550 nm AOD***
- ***Biomass burning AOD***, if available (or AOD's of individual aerosol species)
- ***Wind speeds*** in the middle of emission injection height
  [e.g., if all smoke is distributed within PBL, output mid-PBL winds]
- **PBL height**

3-D [3-hourly]

- Aerosol ***species concentrations***
- Aerosol 550 nm ***extinction***

With *Source Strength* Perturbation Factors: 0.7, 1, 3 & 5



Petrenko et al., 2014, in preparation

Satellites

frequent, global *snapshots*; aerosol amount & aerosol type maps, plume & layer heights

Remote-sensing Analysis

- Retrieval Validation
- Assumption Refinement

Suborbital

targeted chemical & microphysical detail

point-location time series

Regional Context

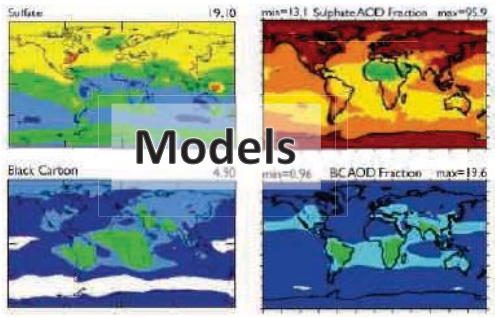
Aerosol-type Predictions

CURRENT STATE

- Initial Conditions
- Assimilation

Model Validation

- Parameterizations
- Climate Sensitivity
- Underlying mechanisms



Models

space-time interpolation,

DARF & Anthropogenic Component

calculation and prediction

Kahn, Survy. Geophys. 2012